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Growing Vegetables Beyond Earth: How ISRO and NASA Are Testing Space Agriculture for the Moon and Mars

*Prethikaa D., Dr. M. S. Marichamy, Dr. V. Kanthaswamy and Dr. S. Nadaradjan
Department of Horticulture, Pandit Jawaharlal Nehru college of Agriculture and Research Institute, Karaikal, UT of Puducherry, India
*Corresponding Author's email: prethikaadevse@gmail.com

When astronauts eventually place their boots on the dusty grey soil of the Moon or the rust-red plains of Mars, they will need more than oxygen tanks and habitats to survive. They will need food and eventually, they will need to grow it themselves. Every kilogram of food launched from Earth costs thousands of dollars to ferry into space and a round trip to Mars can take up to three years. Resupply missions, common for the International Space Station, are simply not practical across interplanetary distances. That single logistical fact has turned space agriculture from a novelty experiment into one of the most closely watched fields of space science today. Two space agencies stand at the forefront of this effort: the National Aeronautics and Space Administration (NASA) of the United States and the Indian Space Research Organisation (ISRO). Both are racing to answer the same fundamental questions- can vegetables, grains and other food crops actually grow in the alien soils and environments of other worlds? This article takes a deep dive into what each agency is testing, the science behind why farming in space is so difficult and what the future of "off-world" vegetable gardens might look like.

Why to grow vegetables in space at all?

At first glance, growing lettuce on the Moon might sound like a quirky side project. In reality, it addresses three converging needs of long-duration space travel.

1. Nutrition over long missions

Pre-packaged space food is freeze-dried, irradiated or thermally processed to survive years in storage. That process degrades vitamins, particularly vitamin C and other antioxidants over time. A Mars mission, which could last two to three years round trip, would see astronauts eating food that has lost much of its nutritional punch by the return. Fresh, self-grown produce offers a way to top up nutrients that shelf-stable food cannot reliably provide.

2. Closing the life-Support loop

Long-duration missions rely on what engineers call a bioregenerative life-support system: a closed loop where plants recycle carbon dioxide into oxygen, filter water and convert waste into usable nutrients, much as forests and wetlands do on Earth. Growing food crops is a natural extension of this loop, turning agriculture into a life-support technology rather than just a source of calories.

3. Psychological well-being

Isolation, confinement, and the visual monotony of a spacecraft or habitat take a toll on mental health. NASA researchers running the Veggie experiment aboard the International Space Station have repeatedly noted that astronauts report improved mood after tending to and harvesting their own plants, a benefit sometimes called "horticultural therapy" in space medicine literature. For missions lasting years rather than months, this psychological dividend may prove just as important as the nutritional one.

The core challenge: alien soil, alien conditions

Unlike the International Space Station, where crops are grown hydroponically in nutrient-rich gel and water rather than soil, a Moon or Mars base will eventually need to use the loose, dusty surface material found on-site known as regolith, because hauling potting soil across the solar system is not sustainable. Regolith, however, is a poor substitute for Earth soil, and it presents distinct problems on each world.

Lunar regolith

- Billions of years without wind or water erosion leave lunar dust jagged at the microscopic level, which can damage plant cell structures and irritate equipment.
- Lunar soil is essentially sterile, lacking the microbial ecosystem and nitrogen compounds that terrestrial plants depend on.
- With no atmosphere or magnetic field, the lunar surface receives far higher doses of cosmic and solar radiation than Earth.

Martian regolith

- Martian soil contains chlorine-based salts called perchlorates at concentrations of roughly 0.5 to 1 percent by weight, toxic to plants and humans alike, and a major obstacle that must be neutralized before farming can begin.
- Sulfates, carbonates, and chlorides make Martian regolith far saltier than most Earth soils, stressing plant roots and limiting water uptake.
- Phosphorus and potassium exist mostly in oxidized, chemically "locked" forms that plants cannot easily absorb without help from soil microbes.

Because of these shared obstacles, much of today's space-agriculture research focuses less on the crops themselves and more on preparing the soil using bacteria, fungi and specialized fertilizers to transform sterile, toxic regolith into something closer to living, fertile earth.

What NASA is testing

NASA's approach spans three fronts: continuous experimentation aboard the International Space Station, ground-based studies using real Apollo-era lunar soil and Mars regolith simulants, and full-scale analog missions that simulate what a Mars surface mission would actually look like.

The veggie system and VEG-03 on the ISS

Since 2014, NASA's Vegetable Production System, nicknamed "Veggie," has served as an on-orbit greenhouse aboard the ISS. Small pillow-shaped growth packets deliver seeds, fertilizer, and a clay-based growing medium in place of soil, while LED panels provide light. Early Veggie crops included red romaine lettuce and "Extra Dwarf" pak choi, with one flowering pak choi crop grown for a record 64 days. The most recent phase, VEG-03, expanded the menu considerably. When the Crew-11 astronauts arrived at the ISS in August 2025, they carried freshly packed seed pillows and a small seed library that let crew members choose what to grow including Wasabi mustard greens, Red Russian kale and Dragoon lettuce. NASA describes the project as validating a rotating variety of crops so that future explorers on the Moon and Mars can have some choice and variety in their diet, rather than eating the same single vegetable on repeat.

Growing plants in real lunar Soil

In a landmark 2022 study, University of Florida researchers Anna-Lisa Paul and Robert Ferl became the first scientists to grow a plant directly in lunar regolith brought back by the Apollo 11, 12, and 17 astronauts. Using just a single gram of soil per plant, they cultivated Arabidopsis thaliana, a small relative of mustard greens, broccoli and cauliflower that is widely used as a model organism because its genetics are so well understood. The plants sprouted, but grew more slowly and showed more stress markers than a control group planted in volcanic ash, confirming that lunar soil, while capable of supporting germination, is a genuinely hostile growing medium without further treatment.

LEAF: Plants on the Artemis 3 moon landing
NASA intends to move this research from the laboratory to the lunar surface itself. As part of the Artemis 3 mission, currently expected in 2026, astronauts are set to deploy a compact greenhouse experiment called LEAF - Lunar Effects on Agricultural Flora. The payload will study how seeds germinate and how plants photosynthesize and respond to stress under the combined pressures of space radiation and the Moon's partial gravity, which is about one-sixth that of Earth. It follows in the footsteps of China's Chang'e 4 mission, which sprouted cotton seeds on the lunar far side in January 2019, the first biological growth ever recorded on another world, though the seedling did not survive the freezing lunar night.

CHAPEA: A simulated Mars mission on Earth
Rather than waiting for an actual Mars mission, NASA has been running the Crew Health and Performance Exploration Analog or CHAPEA, at Johnson Space Center in Houston. Four-person volunteer crews live inside a 3D-printed habitat for stretches of roughly a year, eating a realistic Mars-mission diet with no resupply, while a compact indoor growing system, similar to a home hydroponic garden, lets them cultivate leafy greens, herbs and small fruiting crops. NASA's CHAPEA principal investigator, Grace Douglas, has said that understanding how food restrictions affect crew nutrition, health and morale over many months is essential before such limitations are imposed on an actual multi-year Mars mission.

Regolith Farming Trials: Potatoes, Tomatoes and Microbial Helpers
Because perchlorates and poor nutrient availability make raw Martian regolith simulant nearly unfarmable, much of NASA-linked and university research now centers on biological remediation. Scientists have tested arbuscular mycorrhizal fungi and plant-growth-promoting bacteria that colonize tomato roots grown in Mars regolith simulant, helping the plants extract phosphorus despite the soil's harsh chemistry. Separately, the International Potato Center has screened dozens of potato varieties in Mars-analog soil from Peru's La Joya desert, potatoes being a long-standing NASA interest because of their high caloric density and adaptability. NASA-funded university teams are also testing spirulina, a blue-green cyanobacterium, as a natural fertilizer that can boost germination and biomass in both lunar and Martian regolith simulants and studying fast-growing fungi as an even hardier complement to food crops in future bioregenerative systems.

What ISRO is testing

India's space agriculture programme is younger than NASA's but has moved quickly, anchored by its human spaceflight ambitions under the Gaganyaan programme and plans for a future Bharatiya Antariksha Station or Indian Space Station.

CROPS: India's first space farming experiment
On December 30, 2024, ISRO's Vikram Sarabhai Space Centre (VSSC) launched the Compact Research Module for Orbital Plant Studies or CROPS, aboard the PSLV-C60 rocket as part of the broader SpaDeX docking mission. The experiment used the fourth stage of the PSLV rocket, repurposed as an orbital laboratory platform called POEM-4, to house eight cowpea (lobia) seeds inside a sealed, temperature-controlled greenhouse roughly 300 millimetres across. Cowpea was chosen specifically because it germinates within about a week, allowing rapid results.

The results arrived faster than expected: the seeds sprouted within four days, and the first leaves unfurled a day later. ISRO tracked the plants using onboard cameras alongside sensors monitoring oxygen and carbon dioxide levels, humidity, temperature and soil moisture. Scientists at the agency described the mission as India's first biological experiment to grow a plant from seed in microgravity, calling it foundational for future missions such as Gaganyaan and India's planned space station.

Green Gram, Fenugreek and the Road to the Indian Space Station
ISRO has continued building on the CROPS success. Alongside the cowpea experiment, PSLV-60 also carried spinach cell cultures into orbit in early 2025. Researchers from the University of Agricultural Sciences in Dharwad, the Indian Institute of Space Science and Technology, and Kerala Agricultural University have collaborated with ISRO to plan further

trials of green gram (moong) and fenugreek, both chosen for their nutritional and medicinal value in the Indian diet. ISRO scientist Tushar Phadnis has described these crops as central to understanding how microgravity affects seed sprouting, growth, and yield, data the agency considers essential preparation for the proposed Bharatiya Antariksha Station and for supporting Indian astronauts, or gaganyatris, on future long-duration missions.

A distinct approach: Orbital-first, regolith research to follow

Where NASA has run parallel tracks orbital greenhouses, lunar regolith trials using real Apollo soil and full analog Mars missions, ISRO's publicly announced experiments to date have concentrated on the first and most fundamental question: can seeds germinate and grow at all in microgravity, using India's own indigenous hardware. This mirrors the sequence NASA itself followed decades ago, and gives ISRO a foundation to build toward more complex lunar and Martian regolith-based trials as its Chandrayaan sample-return and Gaganyaan human spaceflight programmes mature.

Side by Side: NASA and ISRO Space Agriculture Efforts

Focus Area	NASA	ISRO
Primary platform	International Space Station (Veggie, VEG-03); Artemis lunar landers (LEAF); Earth-based CHAPEA analog habitat	PSLV rocket fourth stage repurposed as orbital lab (POEM-4); future Gaganyaan capsule and Bharatiya Antariksha Station
Crops tested	Lettuce, pak choi, kale, mustard greens, Arabidopsis, tomatoes, potatoes	Cowpea (lobia), spinach cells; green gram and fenugreek planned
Growing medium	Hydroponic "seed pillows"; real Apollo lunar regolith; Mars regolith simulants (e.g., MGS-1)	Sealed microgravity greenhouse module with monitored environment
Key finding so far	Plants can germinate in real lunar soil but show elevated stress; microbes can unlock nutrients in toxic Mars regolith	Cowpea seeds germinated in just 4 days aboard POEM-4, with first leaves by day 5
Next milestone	LEAF greenhouse on the Moon during Artemis 3 (targeted 2026)	Expanded crop trials ahead of Gaganyaan crewed flights and Indian Space Station

Fig. 1. An astronaut harvests romaine lettuce grown in NASA's Veggie plant-growth chamber aboard the International Space Station. (Credit: NASA)

Common threads: The science both agencies share

Despite different hardware and mission timelines, NASA and ISRO along with university and international partners are converging on similar strategies to solve the same underlying problems.

Microbial soil engineering

Across dozens of studies, cyanobacteria, phosphorus-solubilizing bacteria and mycorrhizal fungi keep appearing as the most promising tools for transforming sterile, nutrient-poor regolith into a workable growing medium. These organisms can extract nitrogen from thin air, unlock phosphorus trapped in mineral form and in some cases help break down toxic perchlorates effectively doing the biochemical work that healthy Earth soil performs for free.

Choosing Hardy, High-Value Crops

Leafy greens such as lettuce, kale and mustard dominate early trials because they grow quickly, need relatively little space and are nutritionally dense. Legumes such as cowpea and green gram are prized for fixing their own nitrogen and for their protein content. Potatoes remain a long-term target because of their high caloric yield per unit area, even though their nutrient demands make them harder to grow in raw regolith.

Fig. 2. Astronaut with Crops Grown Under LED Lighting in NASA's Advanced Plant Habitat (ISS)

A layered testing strategy

Both agencies follow a broadly similar sequence: first, prove basic germination and growth is possible under the target conditions (microgravity or simulated regolith); next, identify which soil treatments and crop varieties perform best and finally, deploy hardware to the actual destination orbit, and eventually the lunar or Martian surface itself to validate results in situ.

What's next: From experiments to off-world farms

The next few years should bring a wave of new data. NASA's LEAF experiment is expected to become the first NASA-led plant-growth study conducted directly on the lunar surface, once the Artemis 3 crewed landing takes place. In parallel, CHAPEA-style analog missions will keep refining how much fresh food a Mars crew can realistically grow to supplement a fixed, resupply-free diet over a year or more. ISRO, meanwhile, is expected to expand its roster of crops tested in microgravity as it builds toward crewed Gaganyaan flights and the planned Bharatiya Antariksha Station later this decade, with lunar and Martian regolith-based trials a likely next frontier as India's Chandrayaan programme advances toward sample-return and eventually, human lunar missions. Across the field, researchers broadly agree that no single fix will make lunar or Martian soil farm-ready. Instead, future off-world greenhouses will likely combine several layers of technology: microbial pre-treatment to detoxify and fertilize the regolith, radiation-shielded enclosures to protect crops from cosmic rays, supplemental LED lighting tuned to each plant's needs and carefully selected or even genetically adapted crop varieties bred for salinity and stress tolerance. None of this is science fiction anymore it is an active, well-funded engineering problem, with working prototypes already sprouting leaves in orbit and in Earth-based labs that mimic alien soil.

Conclusion

The image of an astronaut harvesting lettuce under artificial lights or tending cowpea sprouts on a shelf orbiting Earth, may look like a small thing next to the grandeur of a rocket launch. But these modest greenhouses represent one of the most important pieces of the puzzle for humanity's next steps into the solar system. Whether it is NASA's Veggie system quietly producing salad greens on the ISS, its LEAF payload preparing to break new ground on the Moon, or ISRO's CROPS experiment proving that an Indian-built greenhouse can sprout seeds in microgravity within days, the message from both space agencies is the same: before humans can live on the Moon or Mars, they will first need to learn how to farm there.

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