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Thriving on Mars: Potatoes as the Answer to Martian Challenges

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Abstract: Humans have committed themselves to the exploration of space and the quest for a habitable planet. Central to the development of a sustainable ecosystem that can provide essential resources like food and water is the implementation of space plant cultivation systems. In the pursuit of bio-regenerative life support systems for human space exploration, the inclusion of plants is imperative. This study focuses on assessing potential challenges associated with cultivating Potatoes (Solanum tuberosum) under simulated Martian conditions. Potatoes exhibit adaptability to extremely cold and dry environments, making them a promising candidate for extraterrestrial agriculture. The advantages of potatoes include their high yield, rich content of easily digestible carbohydrates, elevated protein levels, and simplicity of propagation. When induced to tuberize, potatoes can achieve a harvest index exceeding 80%, approximately double that of traditional grain crops. Notably, unlike certain crops such as soybeans and certain grains, potatoes do not necessitate elaborate processing procedures before consumption. The Potato, specifically varieties like Norland, Denali, and Russet Burbank, has garnered attention in research funded by the US National Aeronautics and Space Administration (NASA). Tests have revealed that these cultivars can successfully undergo tuberization even under constant bright light conditions, emphasizing their potential suitability for life support functions in space exploration contexts.

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1. Introduction

Long before space exploration became a tangible reality, Tsiolkovsky envisioned harnessing plants to sustain human life during space travel. The concept of "bio-regenerative life support" emerged, focusing on the cultivation of plants in controlled environments to replenish food and oxygen while simultaneously purifying wastewater and eliminating carbon dioxide. In a groundbreaking study led by David Ramirez, a crop ecophysiologist at the International Potato Centre (CIP), 65 different potato genotypes were subjected to experimentation. This included 38 advanced clones from CIP's lowland tropics virus-resistant (LTVR) breeding population, 22 native potato types, and five enhanced varieties. Transplanting in-vitro plantlets into pots with soil

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from la Joya and peat soil as a control, the team watered them for two weeks. Astonishingly, 40% of the genotypes thrived in the la Joya soil, producing small tubers.

Water stress emerged as a critical physiological challenge in many potato-producing regions. The absence of Martian soil samples necessitates reliance on simulants, with la Joya soil identified by Dr. Julio Valdivia's studies as the most similar to Martian soil on Earth due to its high salinity. Sixty-five potato genotypes were tested, revealing that certain plantlets, when compared in three replicas, could indeed flourish in extreme saline conditions. Plants exhibit an ability to adapt to harsh conditions, retaining a memory of their initial exposure. This adaptability extends to factors such as salinity tolerance, crucial for addressing challenges posed by climate change. As the Earth's temperature rises and water evaporation increases, soil salinity becomes a pressing concern. This research not only paves the way for future exploration but also offers a vision for crop growth, particularly in the face of climate change. Electrical conductivity, a measure of salinity, identified several genotypes with remarkable tolerance to extreme saline conditions, marking a significant stride in agricultural resilience **[1]**.

2. Space Farming On Mars?

The gravitational force on Mars is approximately 0.38 g, a factor that influences the behavior of soil and water dynamics on the planet. Due to this reduced gravity, Martian soil has a greater capacity to retain water compared to Earth, leading to more frequent drainage of water and nutrients. Objects on Mars would appear approximately three times lighter than their weight on Earth due to the distinctive Martian gravity **[2]**. This altered gravitational environment has implications for plant life. Photosynthesis, the vital process through which plants generate energy, relies on chemical reactions converting water and carbon dioxide into sugar and oxygen. Potassium facilitates the opening of tiny pores in leaves and stems, facilitating the intake of water and carbon dioxide crucial for photosynthesis. The chemical equation representing this transformative process is expressed as.

$$6\,CO2\,(g)\;+\;6\,H2O(l) \rightarrow 6\,O2(g)\;+\;C6H12O6\,(aq)$$

Essential nutrients, including phosphorus and potassium, are prerequisites for enabling photosynthesis in plants. Nitrogen, a key component of chlorophyll, not only imparts the green coloration to plants but also plays a pivotal role in capturing the light essential for photosynthesis. In the Martian context, the altered gravitational conditions influence the dynamics of soil, water, and nutrient interactions, shaping the unique challenges and opportunities for plant growth on the Red Planet.

3. Can Oxygen be produced on Mars?

The MOXIE (Mars Oxygen In Situ Resource Utilization - ISRU Experiment) project represents a groundbreaking initiative within the Perseverance rover, aiming to generate oxygen on Mars through solid oxide electrolysis of carbon dioxide from the Martian atmosphere. This landmark experiment signifies the pioneering demonstration of In Situ Resource Utilization (ISRU) on a planetary body.

In its current form, MOXIE has successfully produced oxygen seven times between its landing in February 2021 and the end of the year. The significance of this achievement lies in its potential to play a pivotal role in future human exploration of Mars. By locally generating the tens of tonnes of oxygen required for rockets to transport astronauts from Mars' surface, a scaled-up MOXIE could revolutionize the efficiency and sustainability of long-term missions. This contrasts with the conventional approach of launching massive amounts of material from Earth to meet these oxygen demands.

The adaptability of MOXIE is evident in its ability to operate throughout the day and night, across all four Martian seasons. The experiment leverages the CO_2-rich Martian atmosphere, characterized by a surface atmospheric pressure range of 5 to 10 mbar, as a resource for on-site oxygen production.

Looking ahead, envisioning a future crewed mission to Mars involves considering an MAV (Mars Ascent Vehicle) equipped with a MOXIE-like system scaled up several hundred times, capable of producing 2 to 3 kg/hour compared to MOXIE's initial 6 to 8 g/hour. This scaled-up system allows for the generation of sufficient oxygen to support a crew arriving in a subsequent 26-month cycle. Testing the ability to produce oxygen in the challenging conditions of the Martian environment is deemed crucial for the success of human exploration missions, highlighting the necessity of pushing the boundaries of ISRU technology on Mars.

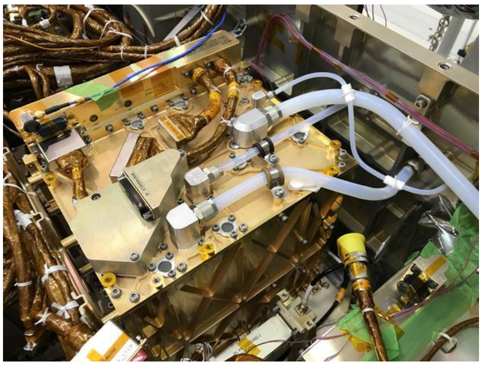

Figure-1 The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) Instrument glows in this photo after being mounted inside the Perseverance rover. It is gold-plated. Image Courtesy: NASA/JPL

4. Potential Landing Sites from Plant Perspective

Engineering constraints for the landing site were initially formulated based on the landing scenario and the early spacecraft design. These constraints were dynamic and evolved in tandem with the spacecraft design iterations and testing phases. Continuous updates and reevaluation of the engineering restrictions on potential landing locations were conducted to align with the evolving mission requirements.

To ensure that operational orbital spacecraft, initially the Mars Global Surveyor (MGS) and later Mars Odyssey, had sufficient time to acquire up-to-date remote sensing data, the preliminary engineering constraints—specifically, elevation and latitude restrictions—were systematically applied to identify suitable areas on Mars. This proactive approach not only facilitated the early search for viable landing sites but also allowed these orbiters ample time to carry out their respective missions.

The initiation of the search for potential landing sites in parallel with mapping engineering constraints provided a valuable head start, enabling operational spacecraft to collect crucial data. This iterative process enhanced the engineers' understanding of the Martian environment, serving as valuable input for spacecraft design adjustments and refinements as more data was gathered and analyzed over time.

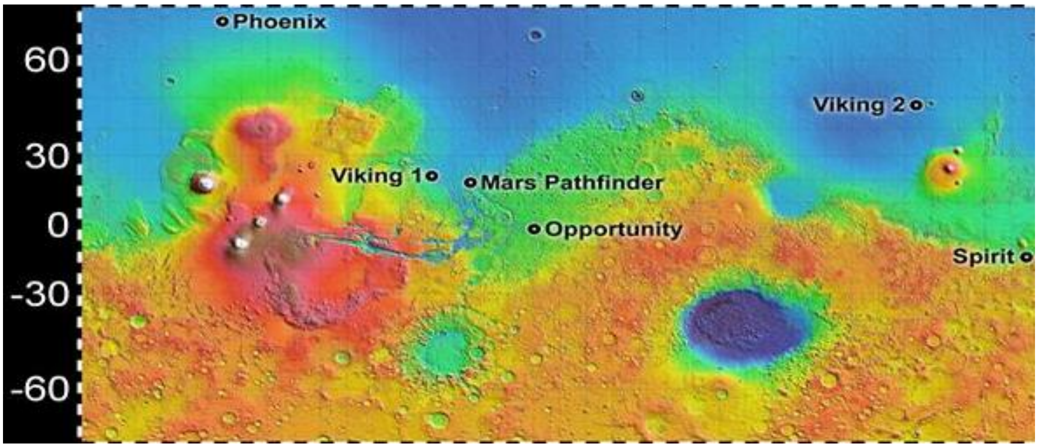

Figure-2 Six Landing Sites on Mars. Image Courtesy: NASA/JPL

5. Advantages of Growing Potatoes on Mars

The resilience of potatoes to drought and their capacity for stress memory remain areas of limited understanding. In the present study, an exploration of the long-term stress memory in three potato varieties (Unica et al.), each exhibiting distinct yields under water restriction, was conducted. The focus was on evaluating tuber production and features associated with drought tolerance [3].

Mars boasts elevated levels of Carbon Dioxide (CO2), a factor conducive to the growth of potatoes. A noteworthy development is the successful survival and reproduction of earthworms in a Mars soil replica, marking a crucial milestone in establishing a robust agricultural ecosystem for crop cultivation on the Red Planet.

Importantly, Martian soil contains essential nutrients vital for plant growth, contributing to the creation of a sustainable environment for agriculture. Below are the essential plant nutrients found in Martian soil.

Parameter	Martian conditions	Growth	Survival
Temperature (^{0}C)	-123 0 to +125	-20 to +113	-262 to +113
Pressure	560	$10^5 – 10^8$	10^{-7} -10^8
Ionizing radiation (Gy)	≈ 0.2[a]	≈ 50	⩽ 5000
UV radiation (nm)	>200	Terrestrial(>290)	≈Terrestrial(⩾290)
Water stress(a_w)	7 x 10^{-4}[b]	>0.7	0-1.0
Salinity	Regional high	< 30 %	Salt crystals
pH	--	1-11	0-12.5
Nutrients	--	High metabolic versatility, high starvation tolerance	Not required,better without

Table-1 Summarizes the current environmental parameters on Mars and contrasts them with the climatic range that supports the growth or survival of microorganisms on Earth [4]. [Note: a – per year; b – g/cm3]

6. Essential Nutrient Analysis on Mars

While numerous nutrients may be present in adequate quantities, their accessibility is not guaranteed. Two crucial elements, magnesium and iron, may reach levels that are toxic to plants when present in abundance. Bioavailable substances such as arsenic, aluminum, chromium, cesium, and others, if present, can act as phytotoxins and impede growth. Moreover, Mars' soil is enriched with various salts, and the detected salt levels are likely to induce salinities that surpass the optimal conditions for the flourishing of most plants.

ESSENTIAL NUTRIENTS AVAILABLE ON MARTIAN SOIL	
MACRONUTRIENTS	**MICRONUTRIENTS**
Oxygen (O)	Iron (Fe)
Carbon(C)	Manganese (Mn)
Hydrogen (H)	Zinc (Zn)
Nitrogen (N)	Copper (Cu)
Phosphorous (P)	Molebdenum(Mo)
Pottasium (K)	Boron (B)
Calcium (Ca)	Chlorine (Cl)
Magnesium	

7. Practical Problems of Growing Potatoes on Mars

7.1. Mars-Like Soil Conditions and Potato Cultivation:

The Pampas de La Joya Desert in southern Peru has been identified as a substantial analogue model for life in dry, Mars-like conditions, offering intriguing insights into Mars-like soil **[5]**. Unusual minerals, including salts, and oxidants, coupled with low levels of organic carbon, present unique challenges for plant development under stressful conditions. Potatoes, known for their prolific growth per unit of land and water, emerge as a promising crop for space exploration **[6]**. Nutrient-rich and containing digestible starch, fiber, potassium, magnesium, iron, vitamin C, and vitamin B6, potatoes are endorsed by NASA for their suitability in extraterrestrial agriculture **[7]**. The International Potato Centre's breeding program has produced advanced potato populations resilient to various biotic and abiotic stresses **[9]**.

7.2. Perchlorate Presence on Mars:

Perchlorate, discovered in Martian soils, poses challenges and parallels with Earth's Atacama Desert. Various proposed formation mechanisms include terrestrial perchlorate synthesis in Mars' stratosphere and UV light-induced oxidation on grain surfaces. Concentrations of perchlorate on Mars suggest environmental and atmospheric changes that impact the planet broadly **[10]**.

7.3. Impact of Martian Gravity on Plant Physiology:

Investigations into partial or reduced gravity levels on Mars and the Moon have implications for plant physiology in the establishment of human settlements on adjacent planets **[14]**. Studies involving Arabidopsis Thaliana seedlings aboard the International Space Station indicate the potential effects of Mars gravity (0.38 g) on plant growth, with ongoing research exploring lunar gravity (0.17 g) **[15-16]**.

7.4. Auxin Dependence and Space Farming:

Progress in understanding plant growth at fractional gravity levels, essential for bio-regenerative life-support systems and space farming, has been achieved through experiments on the ISS and other spacecraft **[17, 18]**. Further research is required to address variances and limitations in utilizing these facilities for space biology, particularly in the context of Mars gravity **[18]**.

7.5. Reactive Nitrogen and Martian Composition:

Reactive nitrogen, crucial for plant growth, is theorized to be present in the solar system's composition and solar wind, offering potential nitrogen sources on the Moon and Mars **[19- 20]**. Volcanic eruptions or lightning on Mars could further contribute to the formation of reactive nitrogen **[21]**.

7.6. Challenges of Dust Particles on Mars:

Dust storms on Mars, characterized by varying opacities, present challenges, including the electrostatic charging of the Martian surface due to fine dust particle movements. This phenomenon, propelled by dust devils and storms, influences the surface's properties.

7.7. Radiation Exposure on Mars:

The absence of a protective atmosphere on Mars exposes the surface directly to unregulated solar radiation, posing challenges for potential plant cultivation.

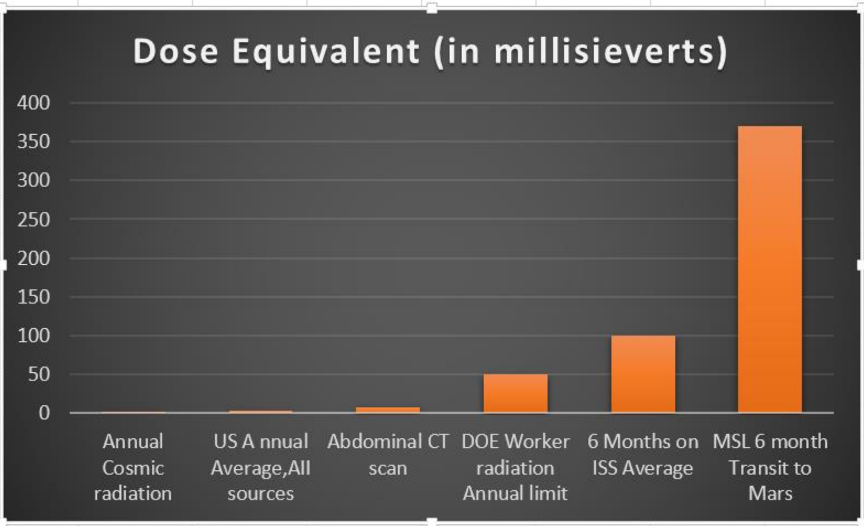

Figure-4: Radiation Exposure and Dose Equivalent. Image Courtesy: NASA JPL

8. A Comprehensive Examination of Potato Cultivation Solutions

Artificial light becomes essential in the absence of a material capable of meeting the multifaceted requirements for pressurization, insulation, resistance to puncture threats, and optimal natural light penetration, while also serving as a foundation for life support systems on Mars. In the 1970s, researchers at the University of Tokyo introduced the electromagnetic Dust Screen as an innovative solution for dust elimination in space, distinct from conventional electric curtains.

To transform Martian soil into a conducive environment for plant growth, obtaining samples of microorganisms, organic matter, and biomass is imperative. Bacteria, particularly earthworms, play a crucial role in bioturbating the soil in space, creating essential holes for adequate soil aeration. The first Veggie plant growth chamber and 18 plant pillows for the VEG-01 experiment were dispatched to the International Space Station (ISS) in April 2014. While limited research exists on space-cultivated plants, microbiological testing remains pivotal for ensuring food safety in any space program.

The intermittent operation of MOXIE, causing significant thermal stress with each heating cycle, represents a distinctive challenge. The primary developmental objective focused on minimizing the cycle-to-cycle degradation of Solid Oxide Electrolyzer (SOXE), with promising results evident in early Mars operations. However, the energy constraints of the Perseverance rover hinder the assessment of long-term performance over the extensive operational hours required for sustaining a human mission. These comprehensive tests are part of an ongoing laboratory program **[24]**.

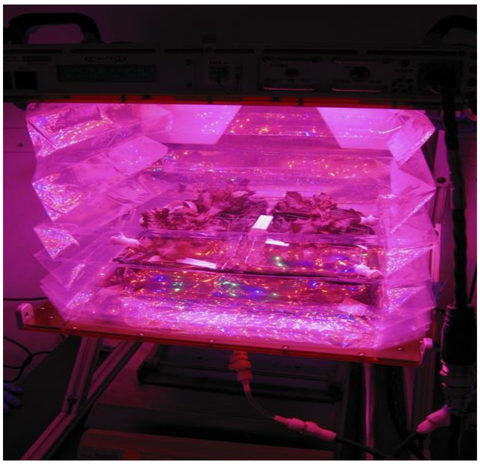

Figure-5 VEGGIE payload on the ISS with the red light panel turned on, including a crop of mature red romaine lettuce. Image Courtesy: NASA/Gioia Massa

9. Summary and Conclusions

Despite the initial high costs associated with resource procurement, particularly in the early stages, decisions regarding the architecture of space life support systems necessitate careful trade-offs, especially considering factors like weight, area/volume, and energy efficiency. Notably, conclusions about the viability of growing potatoes in Martian soil simulants are plausible.

The growth of food crops in space is intricately linked to light exposure, with production efficiency exhibiting a notable sensitivity to light levels. On Mars, potatoes could be cultivated within a climate-controlled greenhouse, leveraging a combination of suitable sowing techniques, tolerant genotypes, and effective soil management to maximize yields in a protected, controlled environment with a pressurized atmosphere.

The feasibility of cultivating plants in lightweight, transparent "greenhouses" on Mars or other interplanetary environments has been demonstrated, showcasing the adaptability of plant growth even under low total and partial pressures. While numerous terrestrial analogs exist for fairly low-pressure ranges, the challenge lies in finding equivalents for very low and extremely low atmospheric pressures. Traditionally, vacuum chambers have been employed for research on extremely low pressures, but questions remain regarding the simulants' ability to accurately replicate water conveyance and other physical properties, as well as their fidelity in representing actual soils. Ongoing debates surround these aspects.

10. Conclusion

. Undoubtedly, one of humanity's most significant challenges lies in orchestrating a manned expedition to Mars—a venture that opens the door to exploring previously untouched frontiers. This collaborative mission not only holds the promise of scientific breakthroughs, such as the search for extraterrestrial life, but also carries the potential for economic benefits through the utilization of off-planet resources and the concept of "living off the land." Beyond that, it presents an opportunity for cultural enrichment by expanding our understanding of how various elements interact.

Within this framework, the feasibility of cultivating plants in artificial environments on Mars and the moon's surface becomes a captivating prospect. However, numerous obstacles impede the progress of human missions to Mars. The applicability of existing knowledge to cultivating plants in Martian soils remains uncertain, necessitating further investigation. Key areas of inquiry include understanding the availability of reactive nitrogen on the Red Planet, the incorporation of nutrients to establish a balanced nutrient profile, the impact of gravity, light, and other environmental conditions, and an in-depth analysis of the physical characteristics of Martian soils, including their water-holding capacity. Comprehensive research is imperative to address these complexities and pave the way for successful plant cultivation in the challenging Martian environment.

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12. Biography

Hiba P, from Mukkam, Kerala, India, is a passionate and dedicated scholar with a deep interest in science. She holds a Bachelor's degree in Physics and is on an exciting journey of exploration and research in the fields of astrophysics and materials science. Hiba has attended important conferences and workshops to learn and share her knowledge. In 2023, she took part in the NASA Exoplanet Science Institute (NExScI) Sagan Summer Workshop, where she explored the fascinating world of exoplanet atmospheres. She's skilled in using Python for her research. She also presented her research on 'Detection of Exoplanets using Transmission Electron Microscopy (TEM)' at the Association of Indian Physicists (AIP) National Symposium in 2023. Hiba's dedication to science was evident in her poster presentation on 'Magnetic Reconnection in Astrophysical Plasmas' at a national symposium. Hiba has participated in international conferences and even learned about drone surveying and map digitalization at a workshop. Her academic journey reflects her strong commitment to expanding our knowledge in her chosen fields. She's on a mission to contribute to the world of science and make new discoveries.

13. Acknowledgement

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14. Conflict of Interest

The author have no conflict of interest to report.

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