A hypothetical study of the possibility of agriculture in space

Abstract

This theoretical research aims to explore the possibility of agriculture in space and understand the challenges it faces, given the importance of this process in supporting long-term space missions. Successful agriculture in space is a vital solution for sustaining extraterrestrial life, especially in environments such as Mars or the Moon, where it is difficult to return to Earth for a supply

Research question or hypotheses: The main question of the research is: "What are the challenges facing agriculture in space?" This is divided into hypotheses regarding scientific and technological challenges and how to overcome them.

The independent variable is the challenges (such as lack of gravity and radiation), while the dependent variable is the success of agriculture in space environments.

Methodology: The research is based on theoretical analysis and previous studies using the method and descriptive. Previous experiments performed on the ISS and other space stations are analyzed. The research focused on hydroponic and pneumatic farming mechanisms and plant health monitoring techniques using machine vision techniques.

Results:

1. Previous experiments have demonstrated that plants can adapt to space conditions, particularly in low-gravity environments.

2- Modern sensor technologies have been developed to automatically monitor plant health in space.

3. Space agriculture requires fewer resources and relies on closed and sustainable agricultural systems.

Conclusion:

The results suggest that farming in space is possible as current research progresses, and that the success of these efforts will contribute significantly to supporting longer future space missions.

Section 1: Introduction Section 1: Introduction

1-Introduction:

Growing food in space is among the most important modern human ambitions, which scientists are looking to achieve to ensure life on a new planet if the Earth's ecosystem collapses. Today, international agencies and private companies are competing to explore the universe. Many of them plan to send long-term missions to Mars, and compete to be the first to set foot on the Red Planet. Interest in space agriculture has increased significantly in recent years. This agriculture is considered one of the important future technologies aimed at supporting human exploration of deep space and space colonies. It may sound like science fiction, but scientific achievements may lead humans in the not-too-distant future to Mars. Even the moon has a special appeal to scientists and researchers who may want to spend a long time there. Humans will then need space bases for long periods, which raises very complex logistical and technological questions. Living for long periods in space requires not only providing the right amounts of ~~food, drink and oxygen, but also transporting all of this into space, so scientists~~ are already thinking about building autonomous biological systems that work independently. At the International Space Station (ISS), a number of materials, such as water, are already being recycled

The Problem:

The basic idea is to enable astronauts to grow their own food aboard spacecraft or on other planets and moons, such as Mars or the Moon. This process is currently facing many scientific and technological challenges, but recent research shows progress in this area. On this basis, the research problem is limited to the possibilities of successful agriculture in space and the challenges it faces because learning how to grow food outside the planet is critical to the success of long-term space missions, such as exploration flights to Mars, which are usually options such as returning to Earth for impractical or incoming supplies. The research problem revolves around answering the following key question**: "What are the challenges facing agriculture in space?" This is divided into sub-questions related to scientific and technological challenges and how to overcome them.**

International Women's Rights Action

Previous Studies:

-Raymond M. Wheeler(2020), Space agriculture: Going where agriculture has never been before

The study aimed to clarify what is happening on the International Space Station (ISS), where astronauts grow leafy vegetables such as lettuce, mizuna, bakchoy, turnips, and even chili peppers in small plant rooms with the aim of providing complementary fresh foods that can still have a profound impact on crew nutrition and mental well-being. The study indicates the need to consider the constraints and challenges facing plant cultivation in space. For example, there is not enough space to accommodate many crops, and there is not enough electricity to operate the lighting systems that are commonly used in plants or vertical farms. Mass, energy and volume costs should also be considered for the area

-Jacob Hempal, Cheryl McCarthy , Craig Bailey , Casey Percy , Peter Britt (2022) Space Farming: Sensing Crops in Space

The study aimed to identify and develop sensing and algorithmic solutions and use them in plant monitoring in order to provide a sustainable food supply in space missions. It also revealed important aspects to be studied related to the challenges facing agriculture in space, including meeting the basic metabolic and nutritional requirements of space crew members and identifying and developing solutions for smarter monitoring. of plants to create a sustainable food supply in space missions and automated plant stress detection will contribute to rapid therapeutic solutions and provide greater food safety and security.

~~-Angelo CG, et al. (2019) Space Agriculture Project: Space Colonization,~~ Technical Agriculture, and the Future of Extraterrestrial Biopolitics. The study aimed to find out the history and future of space colonization and its intertwining with agriculture, its development and the resulting prototypes

Evolution of the concept of space agriculture:

The concept of space agriculture emerged in the 1920s with the description of the possibility of coexistence between humans and plants in a closed environment in space where humans provide plants with carbon dioxide, and plants in turn provide oxygen and food. This idea was put forward by the Russian astronomer.

Konstantin Tsiolkovsky (Wheeler, 2017). Several experiments were conducted on the ground such as BIOS projects in Krasnoyarsk, Russia that focused on growing plants within a closed environment with human crews living in it. The idea was carried out by researchers at IMBP. The tests were carried out inside the Mir space station. They studied the growth of plants in the Svet plant room. The Svet Wali plant room, later developed in Lada, was a smaller, wall-mounted plant room on the International Space Station. Plants cultivated since then include lettuce, mizuna mustard, Chinese cabbage, Russian turnip red, ornamental flowers, wheat, etc. (Srothy, et al., 2024. Page 2

Objectives of agriculture in space:

Space farms aim to provide food for human crews living in microgravity environments aboard spacecraft or on planetary bases. Therefore, agricultural practices and plant crops used on Earth must be modified to suit new conditions in space, such as microgravity, different atmospheric pressure, and carbon dioxide concentrations found only in these environments. These adjustments are not entirely new; they represent a continuation of the adaptation that farmers have made throughout history when they colonized new areas of land. It is necessary to take into account the differences between agriculture in space and agriculture on the planets, where agricultural units are built as part of aviation equipment to be used by human crews in space, both in spacecraft and in planetary bases, taking into account the differences in available resources and the restrictions imposed. Therefore, cultivation in space will take place within controlled environments in rooms of different sizes and energy needs corresponding to available local resources. These rooms will provide programmable levels of light, temperature, humidity, and carbon dioxide, as well as proper ventilation, water delivery systems, and nutrients to keep the plant growing. (Angelo C. et al., 2019, p. 3).

The importance of agriculture in space:

1. Food independence: Reliance on food supply from Earth is not sustainable for long-term missions such as voyages to Mars. Farming in space helps provide continuous food for astronauts. The successful growth of plants in space not only

enhances food production and sustainability, but also oxygen regeneration and water recycling (Stankovic 2018). However, plants in space are exposed to ~~increased levels of electromagnetic and particle radiation and decreased gravity~~ and extreme conditions affect plant biological responses including the mechanisms necessary for plant growth and development (Stankovic 2018). As such, research is needed to understand the effects of space on plant systems to help develop sustainable plant production

2. Sustainability of life: Plants provide oxygen through photosynthesis, which is necessary to sustain human life in a closed environment.

3. Waste management: Organic waste generated by pioneers can be used as fertilizer for plants, contributing to the creation of a closed and circular ecosystem.

4. Mental health: Caring for plants and watching them grow can have a positive impact on pioneers psychologically. In addition to nutrition, it contributes to mental health

astronauts because of the aesthetic value of the plants and the feeling of returning to Earth. (Sruthi, et al., 2024. Page 2

Current and future experiences:

The first botanical experiments aboard the spacecraft were successfully deployed in orbit aboard the Biosatellite II satellite, which flew in orbit for three days before returning to Earth in 1967 (Morrow 2014). The first plant to be planted on space was Arabidopsis thaliana, which grew during a full life cycle in space, and was transported aboard the Soviet low moon Salyut resulting in some viable seeds, but most of them were not viable. Differences between plants growing in space and Earth have been observed (Stankovic 2018). In 2002, the growth experiment (Arabidopsis thaliana) was completed. Plant experiments focused on ~~better understanding the biological mechanisms that may help treat this problem~~ and allow the plant to adapt to space (Jacob et al., 2022). Page 3

1. International Space Station Experiments (ISS): At the ISS, several successful experiments were conducted to cultivate plants such as lettuce, radishes, and rice. These experiments help scientists understand how plants adapt to space conditions. NASA has three controlled plant habitats, two Veggie production system units and the largest advanced plant habitat unit currently on board the International Space Station (ISS). Vegetable units have been developed to be simple, low-resource systems designed to produce fresh vegetables and provide an advanced vegetable habitat

Hundreds of calibrated sensors to monitor and automate microgravity plant growth experiments to inform decisions about the development of future space farming systems.

There is a wall-mounted plant growth chamber "Lada" which has been in use since 2002 in Zvezda, the Russian unit of the International Space Station. Plant habitats are intended to facilitate plant experiments in space; however, plant habitats currently do not have independent decision support for evaluating plant performance in experiments where experiments are monitored by experts on the ground for the purpose of reducing astronauts' additional workload. New means are used to automatically interpret plant stress signals. Through the automated detection of plant stress, rapid remedial efforts are made for plant diseases and their reduction. (Jacob et al., 2022. Page 2

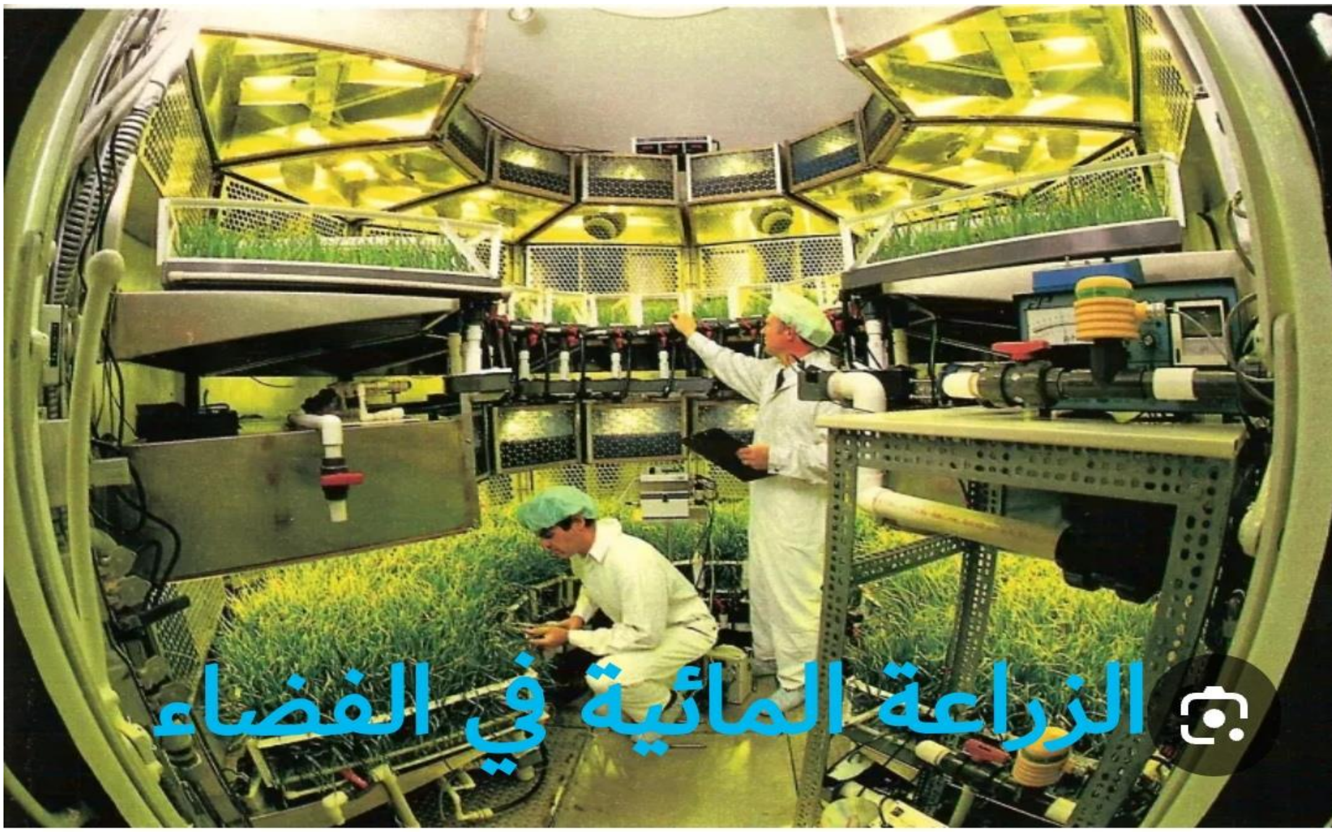
2. Future missions to Mars: NASA and private companies such as Seabes X are developing agricultural technologies that can be used on Mars. For example, how to transform the soil of Mars into an agricultural medium is studied using innovative technologies.

- A project team at the Centre for Agricultural Engineering at the University of Southern Queensland (CAE) is developing new plant sensing solutions based on machine vision, through the Moon to Mars grant from the Australian Space Agency (ASA). The team develops ready-to-launch software and associated algorithms and specifications for associated machine vision cameras and sensors for early quantification of plant-induced stress by examining water, nutrients, and plant disease interactions

-Existing research on robotic vision systems for terrestrial agriculture on Earth provides the potential for developments as well as NDVI for monitoring plants in space. Machine vision involves information of color, texture, shape, and spatial images using machine learning and traditional hand tools where algorithms designed, ground-based are commonly applied to precise agricultural tasks including detection, classification, counting, and yield estimation of the plant. Researchers have devised new methods for monitoring the plant through machine vision through NDVI-based methods that are being developed and tested for use on the ISS (Zidler et al., 2019). The new USQ/ASA project makes it possible to develop a new automated plant pressure algorithms for space, based on knowledge derived from precision agriculture and machine vision, in order to distinguish early water stress and nutrients from lettuce and cabbage. Machine vision is being developed, with more experiments focusing on pathogens. Stress algorithms are designed in parallel with ground laboratory optimization and sensor testers which can be translated into both microgravity and planetary surface

Space Farming Techniques:

1. Hydroponics: Nutritious solutions are used without the need for soil, which is one of the most effective methods in space agriculture.



2. Aeroponics: It relies on spraying nutritious solutions on the roots of plants suspended in the air, which reduces the need for water resources and increases the efficiency of plant growth.

3. Space greenhouses: Closed glass houses can be built on the surface of other planets, so that the indoor climate is controlled to ensure optimal conditions for growth.

Plant growth habitats developed for use in space by the Advanced Astronomical Agriculture System, the Biomass Production System, and the Advanced Plant

General Bioremediation include the Greenhouse and European Lada However, these systems are limited in their growth space, limiting their ability to grow ~~and the ability to supplement the space crew diet, as it was developed primarily~~

on a small scale

- Space farms on planetary surfaces:

In contrast to spacecraft systems, planetary bases are conceived as consisting of large units where larger growth zones and energy budgets can be available. In this case, the cultivation of staple crops (wheat, soybeans, potatoes, sweet potatoes and rice) can be maintained in a controlled environment, provided sufficient lighting is available either from direct solar light, or electrical lighting ~~systems. However, electrical lighting systems require sufficient power, which can~~ be provided by nuclear power plants. Grammar will have the added benefit of some attraction (Angelo C., et al., 2019). Page 2

Extraterrestrial plant cultivation has been attempted, and fortunately, teams of innovatively minded culinary experts have found inspiring ways beyond traditional, often non-nutritious spacecraft porridge. Here are some of their coolest inventions:

1- Robots “smell” how plants grow in space

The arc Center for Excellence in Plants for Space is testing different ways to grow food in space to produce diverse and nutritious food, away from the old dried porridge, which is the only thing astronauts can currently eat.. One of the methods tested by the center is the use of agricultural robots, which are programmable machines that carry out the tasks of the average farmer on the ground. Robots plant seeds, control irrigation, treat crops with disease-resistant spray, and then harvest them when they are fully grown. It is equipped with digital sensors and artificial intelligence technology, which helps it track the growth of plants. Scientists working on the project in Melbourne have even created an ingredient known as an electronic nose. Through “sniffing,” the electronic nose captures the scents released by plants to monitor their needs. The team is also reportedly using facial recognition technology to study the response of astronauts and spacecraft workers to their food and see how microgravity affects taste.

2-The Veggie Growth System (Veggie)is a plant growing room developed by NASA for the International Space Station (ISS). Red, blue and green LED lights ~~are used to stimulate plant growth as a substitute for the sun. The room was a~~ remarkable success and some vegetables were already grown on the International Space Station, so different crops were grown, including lettuce and radishes.

3- A three-dimensional piece of plastic waste The idea of this project is that the people on board the spacecraft collect the plastic waste, cut it, and then insert it into a bioreactor. Here the waste comes into contact with the genetically modified bacteria. Microbes devour excess plastic and turn it into biomass, or "steak." It was engineer Anja Kontractor who came up with this bizarre idea. Her company, Beehex, is developing 3D food printing systems, funded by NASA and the U.S. military, among others.

4. Advanced Plant Habitat (APH) An APH is another plant growth facility on the International Space Station, designed for more complex and longer-lasting experiments. This place provides precise control over environmental variables such as light, temperature, and humidity. It has been used to grow crops such as mustard seeds and wheat.

5-The Chinese Palace on the Moon

China has conducted experiments on plant growth at its lunar palace facilities. These experiments aim to understand how plants can contribute to life-support systems on future lunar bases where different crops, including wheat and potatoes, have been grown in controlled and modified environments to create the right climate for those crops.

6- Cultivation of the cress plant in the moon's soil

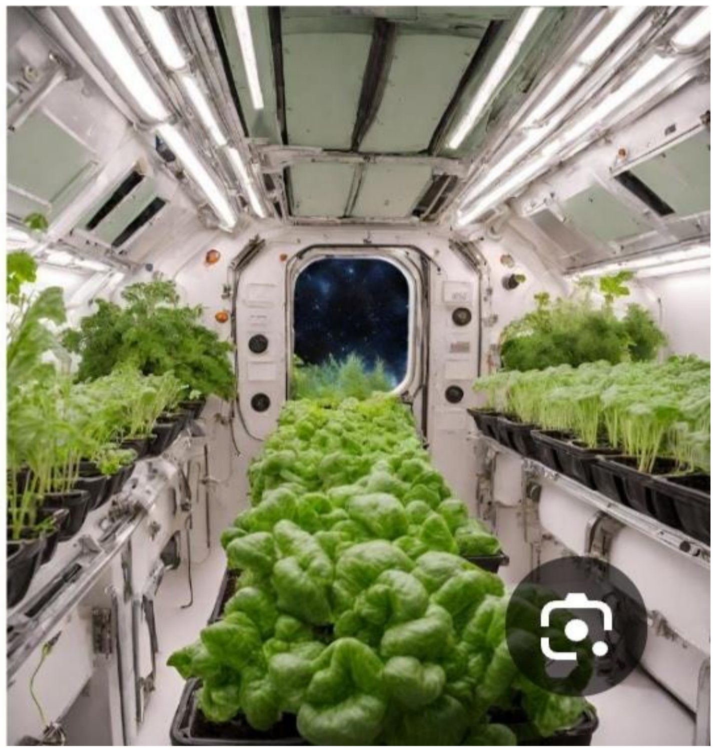
In 2022, scientists succeeded in growing plants in soil coming from the moon for ~~the first time. Researchers at the University of Florida planted mouse-ear cress~~ seeds in lunar soil, using samples collected from three Apollo missions in the late 1960s and early 1970s, along with simulation control. The samples came from different regions on the Moon, but provided favorable conditions for the cress to grow. However, the cress planted in the moon's soil was smaller and slower than the reference group, as well as showing signs of stress. But the Florida team was happy with their findings, which could pave the way for long space travel and the possibility of creating lunar colonies.

7- Synthetic hamburger made from fungi

Space agencies are interested in investing in food solutions for extended space missions. In 2021, NASA and the Canadian Space Agency launched the Deep Space Food Challenge. They challenged revolutionary culinary scientists to invent new ways of preparing food in space. In the second phase of the competition in May 2023, one idea came from Kernel Deltech, which introduced fried cheese and hamburger bites made from the toxic Fusarium venenatum, a fungus used in the manufacture of meat substitutes from Quorn for alternative plant products. The team devised a method of growing and harvesting mushrooms amid microgravity and using compact bioreactors. This method results in a protein-rich gray powder, which can then be turned into snacks such as fried cheese and hamburger bites. (Al-Arabi Post, 2024)

Challenges facing agriculture in space:

1. Zero Gravity (Microgravity): Gravity in space is different from Earth, which affects the behavior of plants. For example, water and nutrients are not distributed in the same way as on land. In space, microgravity greatly affects the



growth of plants, because it is radically different from the terrestrial gravity on which plants depend for orientation and evolution. To overcome the effects of microgravity and ensure the healthy growth of plants in space, certain techniques and strategies have been developed to overcome microgravity and its effects on plant growth, including:

~~1. The main effects of microgravity on plant growth:~~

Gravity and Orientation: On Earth, plants rely on gravity to direct root growth downward (toward Earth) and stems upward (toward the Sun) in what is known as geotropism. In a microgravity environment, this orientation becomes undetermined, and the roots and stems may lead to growth in unexpected directions. As well as the distribution of water and nutrients: In gravity, water and nutrients move from the roots to the rest of the plant due to pressure and gravity differences. In microgravity, lack of gravity can make it difficult to distribute water appropriately, which can lead to its accumulation around roots or in plant tissues in a way that affects growth. In addition to the internal transport of nutrients and hormones: the natural transport of nutrients within the plant depends on gravity to help push it from the roots to the leaves. In space, this transfer may be adversely affected.

2. Overcoming the effects of microgravity:

a. Use of hydroponic and pneumatic farming systems:

As mentioned earlier, hydroponic and pneumatic farming systems rely on delivering water and nutrients directly to the roots of plants, helping to overcome the dependence on gravity to transport water and nutrients. In these systems, the flow of water and nutrients is controlled by precise pumps and devices to ensure an even and efficient distribution.

b. Control of the Agricultural Environment:

Closed greenhouse units or fully controlled planting chambers are used in space. These environments allow precise control of temperature, humidity, and light ~~distribution, which is vital to ensure healthy plant growth in the absence of gravity.~~ These units circulate water and nutrients in a way that ensures that they reach all parts of the plant without relying on gravity.

C. Light Orientation Control (Phototropism):

In the absence of gravity, plants rely on light to determine the direction of growth. Phototropism is the use of light to guide the growth of plants in space. By properly directing the lighting, the direction of growth of the plants can be controlled, as the stems will go towards the light source.

D. Mechanical Stimulation:

Ways to use mechanical stimulation, such as using spinning or vibrating devices to mimic the effects of gravity on plants, have been studied. This may help stimulate the growth of roots and stems in a similar way to what is happening on Earth.

3. Potential positive effects of microgravity:

Some research has shown that plants may grow faster in a microgravity environment due to fewer restrictions on the structure of cells and tissues. This can improve some vital processes, such as photosynthesis. An enclosed space environment, if strictly controlled, may provide an environment free from pests and adverse environmental factors that could adversely affect plants on Earth.

2. Radiation: Space is full of cosmic radiation that may harm plants, so methods must be developed to protect crops from these radiation.

3. Light: In outer space or on planets such as Mars, natural light is not available or suitable for plants, so artificial lighting (such as LED lights) is required to achieve photosynthesis. This process is vital to compensate for the absence or lack of natural sunlight, especially in enclosed environments such as space stations or future space settlements on other planets. This is done through the following:

a. Relying on artificial light sources represented by LEDs (light-emitting diode) LEDs are the most commonly used option because they are very energy-efficient, emitting a specific amount of light required for plant growth. The spectrum of light produced by LEDs can be controlled to provide plants with appropriate light at different stages of their development.

b. Fluorescent lighting: Used in early experiments, but less efficient than LEDs and produces more heat.

C. Plasma and Laser Lighting: They are tested as additional options because of their efficiency in providing proper light to plants.

d. Reliance on appropriate light spectrum: such as blue light (450-495 nm): promotes vegetative growth and leaf development. It is mainly used in the early stages of development.

Red light (620-750 nm): Stimulates the growth of flowers and fruits, so it is used in later stages of growth.

Green light (495-570 nm): It is used in limited quantities, as it is absorbed by the plant less, but it helps in penetrating the leaves of the plant and improving the photosynthetic balance.

E. Timing and Lighting Control:

Plants rely on specific cycles of light and darkness, which is known as photoperiod. In space, these cycles are precisely controlled to ensure that plants ~~get "day" and "night" in a way that resembles their natural environment. On space~~ stations such as the International Space Station (ISS), advanced lighting systems are used that automatically control the intensity and duration of light based on plant growth stages.

g. Reducing heat generated by lighting: Another problem is the excess heat generated by lighting sources. Therefore, lighting systems are designed to be energy efficient and produce the least amount of heat. If excessive heat occurs, cooling systems such as fans or ventilation systems are used to ensure that they do not adversely affect plants.

4. Soil: Planets such as Mars contain materials that are not suitable for agriculture and therefore artificial soil has been developed that relies on alternative materials that can be used to provide an environment similar to terrestrial soil. This artificial soil depends on components such as sand and minerals that mimic the characteristics of natural soil, with the addition of organic materials and nutrients necessary for plants. Scientists have also been keen to take advantage of planetary soil (In-Situ Resource Utilization - ISRU): In the context of exploring planets, such as the Moon and Mars, scientists are looking into the possibility of using the soil on those celestial bodies (such as Mars) as a cultivation system. The soil components of these planets are being tested for suitability to support plant life, enhanced by the addition of nutrients or chemically modified.

Circulation of water and oxygen:

Gerhild Bornmann, a biologist at the German Center for Aeronautics and Spaceflight, explains that water is extracted from urine, so that in the end only a ~~small, concentrated amount remains, which is then sent back to Earth. The water~~ is chemically treated vigorously, and it is pumped back into the water circuit of the space station. The same applies to oxygen, which is recycled inside the station by electrical treatment, as an electric current is passed through the water, oxygen is separated from hydrogen, and then oxygen is pumped inside the station compartment, while hydrogen is disposed of in space. Scientists are already working on alternative solutions. At the German Aeronautical and Space Flight Center in Stuttgart, self-contained biological systems using algae are being tested, as they enable the conversion of exhalation into inhalable oxygen. There are also types of algae that can produce hydrogen. The goal is to create a biocycle that can produce oxygen, hydrogen, water, and energy autonomously on distant spaceflight. Algae has multiple functions, from which a nutrient-rich paste can be extracted. The algae was able to provide twenty percent of the astronauts' food needs. However, the astronauts' diet will not be limited to algae, as tomatoes and some other types of greens can grow in glass tubes filled with cooled lava, which helps plants extend their roots, in addition to their function as fertilizers. Even fish can be taken into space and made part of the life cycle. (Fabian, 2013)

Section 3: Section 3: Objectives 3- Importance and Objectives:

The importance and objectives of the research are as follows:

1. Knowledge of the emergence and evolution of the concept of agriculture in space

2. Uncovering the efforts of scientists and researchers aimed at localizing agriculture in space.

3. Knowledge of past, present and future experiments carried out by scientists in the field of space agriculture

4. Identify the mechanisms and techniques that scientists rely on in the cultivation of space

5. Reveal the challenges and constraints faced by agriculture in space.

6. Contribute to the dissemination of scientific efforts related to space agriculture

Section 4 : Methodology

4- Methodology:

Approach: The experimental approach and the descriptive approach were used

Research Variables:

The Independent Variable: Challenges

Dependent variable: Agriculture in space

Section 5: Preliminary results (if you have)

5-Results:

Space agriculture research and subsequent developments have contributed to and benefited terrestrial agriculture, particularly through controlled farming systems

Developing sustainable food production systems in space is critical to the future success of deep space missions. -The project led by the University of Southern Queensland supports food production for space missions, which is based on the development of automated vision technologies to detect plant stress for use in space, allowing real and accurate monitoring of plant health.

-Developing launch-ready software to identify plant pressures in space will allow plant habitats to respond to detected pressures automatically, reducing reliance on experts on the ground and saving space crew time for other missions.

-Possible future priorities for further development of aerospace farming systems are automated remediation of specific plant pressures, increasing the size of existing plant habitats, and increasing recycling and restoration of water and nutrient resources

The concept of space agriculture has evolved through great technological advances and successful experiments, such as those conducted on the International Space Station (ISS). of the vegetable system, advanced plant habitat, and ethylene purification technology, which promotes plant growth in microgravity.

-Many studies have shown that plants can grow well when pressures are low

Although there is still a long way to go, in general, these attempts at agriculture through space are contributing to the development of sustainable life support systems for future exploration missions.

CONCLUSION:

Space exploration and the pursuit of extraterrestrial human settlements have become a necessity given the challenges facing humanity on planet Earth such as increasing population and climate change. Despite significant advances in agriculture on Earth, agriculture in space is a major challenge due to the uninhabited environment and harsh factors such as lack of gravity, cosmic radiation, and scarcity of natural resources. Research has addressed many ways to improve plant cultivation in space, including the development of closed farming systems, the use of hydroponic and aerobic farming techniques, and the modification of plant genes to improve their adaptation to space environments.

Recommendations:

1. More research should be supported on how space conditions such as low gravity and radiation affect plant growth and reproduction, helping to develop more effective agricultural technologies.
2. Low-resource agricultural systems, such as the use of recycled water and artificial light, should be developed to promote sustainability in space agriculture.
3. Collaboration between international space agencies, universities and private companies should be encouraged to share the knowledge and resources needed to promote agricultural research in space.
4. Research related to genetic modification of plants should be intensified to increase their ability to adapt to the harsh conditions in space, taking care to adhere to scientific and environmental ethics.
5. It is necessary to conduct more agricultural experiments in international space stations such as the International Space Station, in order to realistically test farming systems before implementing them in long-term missions.
6. Encouraging startups and investors to support and develop innovative solutions for agriculture in space, may lead to faster progress in this field.

Section 6: References Section 6: References

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