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PLANTS IN SPACE : GROWING VEGETABLES IN SPACE- A REVIEW

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ABSTRACT

Plants in space refer to plants that are grown in the physical universe known as outer space or outer Earth's atmosphere, which is the typical orbit range of the Space Shuttle missions and of the International Space Station (ISS), where most of human spaceflight and research has taken place. It was focused on improving human habitability through the supply of a continuous source of fresh food for the crews. The International Space Station continues to be a platform for researchers to investigate how various spaceflight conditions affect plant growth and development in different environmental conditions than plants grown on earth. The ability to grow safe and fresh vegetables to supplement the packaged foods of astronauts in space has been an important goal for the National Aeronautics and Space Administration (NASA). Among crop plants, vegetables rich in nutrients and minerals, short duration and more responsive to environmental parameters are the best to grow in ISS. The primary goals of NASA in using these modular plant growth systems are to investigate both the nutritional impact of supplementing astronaut diets with fresh produce as well as the psychosocial benefits of crew tending plants during extended duration spaceflight missions.
***Keywords* :** Space agriculture, Vegetables, ISS, NASA.

Introduction

Space research provides an opportunity to study bioregenerative life support. A bioregenerative life support system must be developed to provide renewable oxygen and a source of food to astronauts for long distance space travel or interplanetary habitation to be possible (Janhavi and Manjunathagowda, 2020). Plants have the potential to fulfil these roles. In the context of human spaceflight, they can be consumed as food and/or provide a refreshing atmosphere. Plants can metabolize carbon dioxide in the air to produce valuable oxygen, and can help control cabin humidity. Growing plants in space provides a psychological benefit to human spaceflight crews (Wheeler, 2017). The International Space Station (ISS) continues to be a platform for researchers to investigate how various spaceflight conditions, such as microgravity, affect plant growth and development (Bamsey *et al.*, 2014). More recently, interest has increased regarding spaceflight crop-production systems, the horticultural needs of potential crops and the ability of such crops to develop and thrive aboard spacecraft such as the ISS (Massa *et al.*, 2016). However, research is still needed to further enhance our understanding of how plants respond to the unique or challenging conditions of spaceflight. Outer space represents a challenging environment for human exploration for a number of reasons, including the lethal hazards of extreme temperatures, high vacuum, electromagnetic radiation, particle radiation and magnetism. In addition, the economic cost of sending anything into space is very high. The challenges of watering plants in microgravity (Stankovic, 2018). As well, to grow plants in space requires cultivars that are well suited to growing and sustaining in the space environment.

Importance of growing plants in space

One astronaut on the International Space Station requires approximately 1.8 kilograms of food and packaging per day. For a long-term mission, such as a four-men crew, three-year mission, this number can grow to as much as 10,886 kg (Cooper *et al.,* 2011). Due to the cost of supply and the impracticality of resupplying interplanetary missions, the prospect of growing food in flight is incredibly appealing. The existence of a space farm would aid the creation of a sustainable environment, as plants generate oxygen and continuously purify the air on the space station or spaceship (White *et al*., 2016). Only 10 m2 of crops produce 25% of a person's daily food requirements. Essentially, the space farm turns the spaceship into an artificial ecosystem (Maggi and Pallud, 2010). Currently, much of the food supplied to astronauts is heat treated or freeze dried. However, vitamin and other mineral degradation during storage can occur. The ability to grow food in space would help reduce the vitamin gap in astronauts' diets and provide fresh food with improved taste and texture (Cooper *et al.,* 2011).

Role of growing vegetables in space

Vegetables have mostly short growth duration and are more responsive to environmental parameters. Vegetables require less space to grow, and vegetables are easy to cultivate. Moreover, it contains more minerals and nutrients and is a good source of food for astronauts during their space travel (Khodadad *et al*., 2020).

Cultivation of vegetables in space

Vegetables in ISS are grown in production units, which are chambers that provide a precise environment to grow plants inside. Plant cultivation flight experiments are usually small chambers that are not an active part of the life support system. They are typically utilised to study plant behaviour and development under reduced gravity and in closed environments.

Production units:

Biomass production system (BPS)

The Biomass Production System (BPS) was a plant growth chamber operated on the ISS in 2002 during Expedition 4. It was designed to validate subsystems under orbital conditions. Two experiments were carried out during this mission, the Technology Validation Test (TVT) and the Photosynthesis Experiment and System Testing and Operation (PESTO) experiments. PESTO demonstrated that plants grown in space do not differ from ground controls when the secondary effects of the spaceflight environment are mitigated. Evidence was identical rates of photosynthesis and transpiration that were corroborated with identical biomass between spaceflight and ground control plants. The system was first designed to fit into the Shuttle Middeck and the SpaceHab Module, but was later adapted for installation into an EXPRESS Rack to be able to fly to the ISS. The BPS contained four individual plant growth chambers. Each chamber had its own independent control system for temperature, humidity, lighting and CO_2. An active nutrient delivery system was also part of the experiment. The overall BPS had a depth of 52 cm, a width of 46 cm and a height of 55 cm. The total mass was 54.4 kg. The total grow area was 1040 cm² divided equally among the four chambers, with each 260 cm². The subsystems and technologies validated by the BPS were later used within the Plant Research Unit (PRU) (Musgrave *et al.,* 2005). Two crops were grown in BPH at ISS in 2002. The first crop grown is wheat (*Triticum aestivum* v. apogee) and second crop grown is *Brassica rapa*. Musgrave *et al.* (2005) studied growth and quality parameters of *Brassica rapa* seeds grown in the ISS (Biomass Production System) and in ground control. The results showed that the seeds from the spaceflight treatment had higher concentrations of chlorophyll, starch and soluble carbohydrates than the ground controls.

Vegetable Production System (Veggie)

The “Veggie” Food Production System is NASA’s latest achievement, which was launched in early 2014. Veggie is the first system designed for food production rather than plant experiments under microgravity. A deployable design allows Veggie to be stowed to 10% of its nominal deployed volume. In collapsed configuration, six Veggie units can be stored in a single middeck locker. Each unit consists of three major subsystems, the lighting subsystem, the bellows enclosure and the root mat and provides a 0.17 m² grow area with a variable height of 5 to 45 cm. A customised LED panel with red, blue and green LEDs is used as the lighting subsystem. The panel can provide more than 300 mol/(m2 s) of light to the plants. The bellows enclosure separates the plant environment from the cabin to provide containment for the plants and to maintain elevated humidity. The enclosure is supported by a foldable structure, which allows adjustment of the distance between the lighting subsystem and the root mat while maintaining containment. The root mat serves as a passive nutrient delivery system, which requires only a small amount of crew time to be supplied with water and nutrient solution (Stutte *et al.*, 2011). Several different growth media have been investigated and, in the end, specially developed rooting pillows were selected. Crops produced by the Veggie system will be used as supplemental food for the ISS crew (Massa *et al.*, 2016). To date, Veggie has successfully grown vegetable plants like lettuce in 2010. In 2015, Outredgeous variety of red romaine lettuce was grown and consumed by astronauts, which was harvested after 33 days in space, with intensely dark red, slightly ruffled leaves forming loose upright heads. Astronaut Peggy Whitson harvests Tokyo Bekana Chinese cabbage aboard the International Space Station on Feb. 17. Astronaut Serena Aunon harvests kale on Nov. 28, 2018. The crew got to enjoy a mid-afternoon snack. 'Extra Dwarf' pak choi were grown for 64 days, the longest grown on station in 2019. Burgner *et al.* (2020) conducted an experiment on the growth and photosynthetic responses of Chinese cabbage (*Brassica rapa* L. cv. Tokyo Bekana) to continuously elevated carbon dioxide in a simulated Space Station "Veggie" crop-production environment. Studies reported that 'Tokyo Bekana' was very sensitive to continuously elevated CO_2 in such a growth environment and indicated the need for improved environmental control of CO_2 and possibly root-zone factors for successful crop production in the ISS spaceflight environment. Khodadad *et al.* (2020) conducted an experiment on the microbiological and nutritional analysis of lettuce crops grown on the International Space Station. This study indicated that leafy vegetables could produce safe, edible, fresh food for astronauts' diets and provide baseline data for continual operation of the veggie plant growth units in the ISS.

Advanced Plant Habitat (APH)

The Advanced Plant Habitat (APH) is a fully automated plant growth facility that will be used to grow plants on the International Space Station. The system was developed by NASA and ORBITEC of Madison, Wisconsin. It uses LED lights, a porous clay substrate and a controlled release fertilizer to deliver water and nutrients to the plant roots. Unlike Veggie, APH is sealed, and automated with cameras and more than 180 sensors that are in constant interactive contact with a team on the ground at Kennedy, so it doesn't need day-to-day care from the crew. APH had its first test run on the space station in spring 2018 using *Arabidopsis thaliana* (thale cress) and dwarf wheat. The advanced plant habitat is designed for continuous or multi-generational plant growth. APH will have external viewing windows that can be closed off to prevent light leakage. The internal growing area is 11.5 inches wide by 14.5 inches deep, making it the largest plant growth chamber for space to date. The maximum shoot height is 45 cm. The science carrier base root tray (45.4 cm × 40.8 cm × 5.1 cm) consists of a porous tube water delivery system, root zone oxygen sensors, temperature sensors, and substrate moisture sensors in four independently controllable root modules. The growth chamber provides precise environmental control. The temperature can be adjusted between 18 and 30°C (1°C). Relative humidity can be controlled between 50-86% (±5%). The CO2 concentration can be controlled between 500-5000 µmol /mol (±50 µmol). The lighting system consists of red, blue, green and white LEDs (John *et al.*, 2021). To date, two vegetable plants have been grown; they are radish and hot pepper/chilli. Radish plants grown in the Advanced Plant Habitat were harvested on Nov. 30th, 2020 on the International Space Station. Harvested produce is brought back to earth for microbiological and nutrient analysis in laboratories. Chiili is grown in 2021 for a period of 137 days. It is the longest and spiciest vegetable in ISS. John *et al.* (2021) conducted an experiment on space flight cultivation for radish (*Raphanus sativus*) in the Advanced Plant Habitat and reported that the strategies to optimise the growth substrate, watering regimen, light settings, and planting design that produced good-sized radishes, minimised competition, and allowed for easy harvesting. This information could be applicable for growth optimization of other crop plants that will be grown in the APH or other future plant growth facilities.

Plants at Moon

The Moon is Earth's only natural satellite. It lacks any significant atmosphere, hydrosphere, or magnetic field. Its surface gravity is about one-sixth of Earth's. The lunar regolith is very different from terrestrial soil. For a start, it doesn't contain organic matter (worms, bacteria, decaying plant matter) that is characteristic of soil on Earth. Neither does it have an inherent water content. But it is composed of the same minerals as terrestrial soils, so assuming that the lack of water, sunlight and air is ameliorated by cultivating plants inside a lunar habitat, then the regolith could have the potential to grow plants (David and Leonard, 2018).

For the first time, scientists have been able to grow plants in lunar soil. The soil samples were collected during the Apollo 11, 12 and 17 ventures. During the study, which was funded by NASA, University of Florida scientists grew *Arabidopsis thaliana*, a plant in the mustard greens family, in lunar soil samples collected during the Apollo 11, 12 and 17 missions. The research showed that this is indeed the case, seeds of *A. thaliana* germinated at the same rate in Apollo material as they did in terrestrial soil. But while the plants in the terrestrial soil went on to develop root stocks and put out leaves, the Apollo seedlings were stunted and had poor root growth. The main thrust of the research was to examine plants at the genetic level. This allowed the scientists to recognise which specific environmental factors evoked the strongest genetic responses to stress. They found that most of the stress reactions in all the Apollo seedlings came from salts, metal and oxygen that were highly reactive (the last two of which are not common in terrestrial soil) in the lunar samples (Paul *et al*., 2022).

Plants at Mars

Mars receives about half of the sunlight we get on Earth, but much higher levels of harmful ultraviolet (UV) and cosmic rays. The surface temperature of Mars is about -60°C and it has a thin atmosphere primarily made of carbon dioxide. Water on Mars mostly exists in the form of ice. Studies suggest that watering plants on Mars could require less water than on Earth. That is because water would flow differently through the Martian soil thanks to the Red Planet's gravity, which is approximately 38% that of Earth's. In other words, anything on Mars would feel about three times lighter than on Earth. Therefore, under Martian gravity, the soil can hold more water than on Earth, and water and nutrients within the soil would drain away more slowly (Hooper, 2015). Conditions like Mars's extreme cold temperatures make life difficult to sustain. The sunlight and heat reaching that planet is much less than what the Earth gets. This is because Mars is about 50 million miles away from the sun. Also, the Martian atmosphere is not as thick as Earth's atmosphere, which keeps our planet warm. These conditions would make it difficult for plants to grow on Mars (Roberto, 2017).

Summary

Space research focuses on developing bioregenerative life support systems for long-duration missions, where plants are essential for oxygen production, air purification, and food. On the ISS, systems like the Biomass Production System (BPS), Vegetable Production System (Veggie), and Advanced Plant Habitat (APH) have enabled successful cultivation of crops such as lettuce, radish, and cabbage. These studies demonstrate how plants adapt to microgravity. Experiments have also explored growing plants in lunar and Martian soils, highlighting both challenges and potential for future planetary agriculture and human survival in space.

Conclusion

Vegetables grown in space supplement astronauts with fresh food that provides easily available nutrients, vitamins and biomass. Independent of resupplies, these endeavours depend on the provision of a nutritious diet that does not rely on earth dependent supply chains and reduces dependency on prepared food that deteriorates over time. Indeed, investigation of plant cultivation practises in space for bio-regenerative living life supporting systems is a foresight avenue of research. Innovations in advanced controlled environment agriculture technologies of closed-loop systems are the critical component of future human exploration to worlds unknown.

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