A study of plant cultivation for space exploration in JAXA

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SUMMARY
In its efforts toward the manned space exploration of the Moon and Mars, JAXA studies such topics as water and gas recycling, docking systems, and automatic robotic operations. We have conducted several experiments for plant physiological researches under microgravity onboard the ISS and Space Shuttle. We recently began a study of plant cultivation to produce food for space exploration. The goal of the study is to supply food for the crew members and improve their quality of life (QOL) during voyage inside a small vehicle. And also we are considering to demonstrate plant cultivation in the International Space Station (ISS). In addition, JAXA has been studying the concept of a “lunar farming”.

1. Objectives of plant cultivation in space
(1) Food production for future human exploration
(2) Plant cultivation for improving the crew’s QOL

Remarkable conditions of plant cultivation in space
1. Plant cultivation in a space exploration vehicle or space station
   - Limited resources (e.g., water, power, volume), microgravity (μG), high CO₂ level in the space exploration vehicle and space radiation
2. Plant cultivation on the Moon and the Mars
   - Limited resources (e.g., water, power, building materials) and the environment on the Moon and Mars (e.g., regolith including heavy metals (on Mars), low gravity, Gas environment (low pressure, gaseous composition), space radiation, ultraviolet rays)

2. Previous plant experiments under μG at JAXA
STS-95 space experiment (for plant growth and development) ¹)
Through the growth and development of etiolated maize seedlings, the results suggest that plant growth and development, particularly polar auxin transport, are controlled under gravity on the earth.

Space Seed ²)
Arabidopsis was grown to have flowers and seeds under μG and 1G in the ISS. The development results showed rapid stem elongation and slow aging of the leaves under μG.

CsPINs ³)
In this experiment, it was able to observed the pure hydrotropism isolated from gravitropism under μG. Cucumber seedlings were grown under μG during spaceflight. The roots become hydrotropically sensitive in μG, and CsPINs-mediated auxin transport has an important role in inducting root hydrotropism. The CsPINs signals in the high-humidity side were 1.6-times greater than those in the low-humidity side.

3. The status of the study of plant cultivations in space
3.1 Tests for plant cultivation in a space exploration vehicle
JAXA initiated the study to overcome the cultivate conditions (described in 1. Objectives of plant cultivation in space).

• Effects of high CO₂ level on the plant growth
   - We cultivated strawberries under a high CO₂ level (5000ppm), which is the worst-case in the ISS.
   - The results suggest that plant growth and development, particularly polar auxin transport, are controlled under gravity on the earth.

• Growth on hydro-membrane
   - Plant roots are attached to the surface of the film and the plants absorbs water and nutrients through the film. <Advantage>
   - Can prevent water leakage from around stem under 0G
   - No need to supply oxygen in culture solution
   - Using this method in space poses certain problems, such as the settling of planting; it offers a considerable advantage in preventing water leaks.

4. Final target of plant cultivation in space
In the future, we will establish protein production through fish and cattle husbandry technologies, in addition to plant cultivation. And then we will establish a regenerative life support system in which these technologies are to be integrated in the Environmental Control and Life Support System (ECLSS).

CONCLUSION or FUTURE PLAN
• Determine the candidate methods of plant cultivation in space, for both onboard vehicle and on the Moon/Mars.
• Produce a cultivation system for demonstration in the ISS and demonstrate on orbit plant cultivation.
• For overcoming the “space unique” conditions, JAXA will continue cultivation tests under the low gravity, the gaseous composition, and method of cultivation for the regolith of Mars, in simulating the cultivation environment on Mars.

References
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2. Previous plant experiments under μG at JAXA
STS-95 space experiment (for plant growth and development) 1*)

<table>
<thead>
<tr>
<th>1 g on earth</th>
<th>μg in space</th>
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<tr>
<td>Space Seed 2*)</td>
<td>μg in ISS</td>
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3. The status of the study of plant cultivations in space
3.1 Tests for plant cultivation in a space exploration vehicle

- Effects of high CO₂ level on the plant growth
- Growth of the plant on hydro-membrane

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<thead>
<tr>
<th>Control CO₂</th>
<th>5000ppm CO₂</th>
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<tbody>
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<td>Hydroponic culture</td>
<td>Hydro-membrane cultivation</td>
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Condition of roots
3.2. Conceptual study of lunar farming

Cutting-edge plant factory on the earth ©Tamagawa Univ.

Figure

4. Final target of plant cultivation in space

Image of Lunar Farming (Tentative)