A study of plant cultivation for space exploration in JAXA

Tomomi Suzuki[1], Tetsuya Sakashita[1], Haruo Kasahara[1], Tetsuhito Fuse[2],

[1]JEM Utilization Center, Human Spaceflight Technology Directrate, Japan Aerospace Exploration Agency (JAXA), 2-1-1 Sengen, Tsukuba, Ibaraki, 305-8505, Japan., [2] Space Exploration Innovation Hub Center, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan Aerospace Exploration Agency (JAXA), Japan. E-mail: Suzuki.tomomi@jaxa.jp

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

①Plant cultivation in a space exploration vehicle or space station

Limited resources(e.g., water, power, volume) , microgravity(μG) or zero gravity(0G), high CO_2 level in the space exploration vehicle and space radiation

②Plant 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*)]

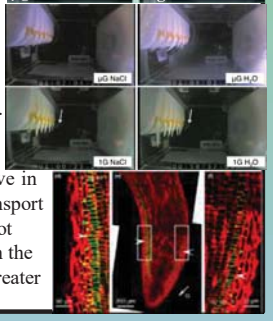
Through the growth and development of etiolated maize seedlings, the results suggest that plant growth and development, particularly polar auxin transport, are controlled under gravity on the earth.

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 CsPIN5-mediated auxin transport has an important role in inducting root hydrotropism. The CsPIN5 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

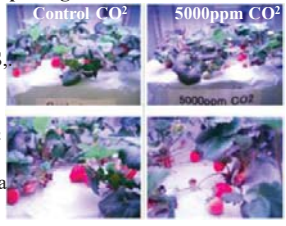
3.1 Tests for plant cultivation in a space exploration vehicle

JAXA initiated the study to overcome the cultivate conditions (described in 1. Objectives of plant cultivation in space).

・Effects of high CO_2 level on the plant growth

We cultivated strawberries under a high CO_2 level (5000ppm), which is the worst-case in the ISS.

Result : Under our test conditions, there was no apparent difference between a normal and a high CO_2 level in such cultivation. Thus, strawberries can be grown under a high CO_2 level. *Average CO_2 level in the ISS: 2500~3000ppm



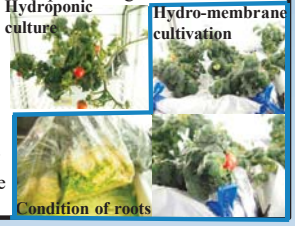
・Growth on hydro-membrane

Plant roots are attached to the surface of the film andThe 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

Result : Dwarf grape tomato was grown on the film and some fruits were produced. However, its slow rate of growth requires a long time to produce tomatoes. Although using this-method in space pose certain problems, such as the settling of planting, it offers a considerable advantage in preventing water leaks.



3.2. Conceptual study of lunar farming

Background

For a future human space exploration, a working group at the JAXA Space Exploration Innovation Hub Center has been studying the concept of "lunar farming" based on the assumption of plant cultivation on the Moon, thus aiming for future food production in outer space.

Similar considerations have been raised in the past, but thanks to the remarkable progress made in plant factory technologies and biotechnology since then, a conceptual study of lunar farming that applies the most advanced agricultural technology and biotechnology represents a new attempt at even looking at the world.

This working group is organized by university professors and private experts who are interested in lunar farming and who have examined the concept of a lunar plant factory, and the working group consists of four groups: cultivation technology, unmanned technology, recycling, and the overall system.

Our conceptual ideas reflect the requirements of lunar farming that include a minimum of resources and minimal labor load. As these requirements are the same as in the agricultural industry, we consequently expects these ideas reveal common challenges between space and the ground.

The first edition of the conceptual study report will be published in the fall 2018.

Commercial production in the plant factory → Food production in lunar farming

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

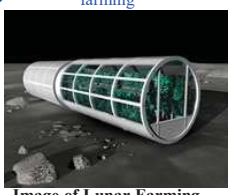
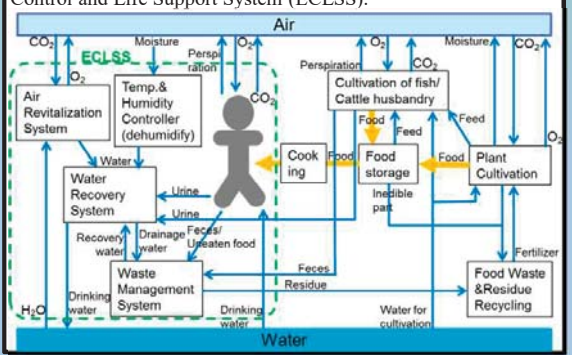


Image of Lunar Farming (Tentative)

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 pressure, the gaseous composition, and method of cultivation for the regolith of Mars, in simulating the cultivation environment on Mars.

References

1*) Ueda J. et al, Biol. Sci. Space, Vol.14 (2000):47-57

2*) http://iss.jaxa.jp/kiboresults/plant/plant-experiment-2015.pdf, "Plant mechanism that respond to space" (in Japanese)

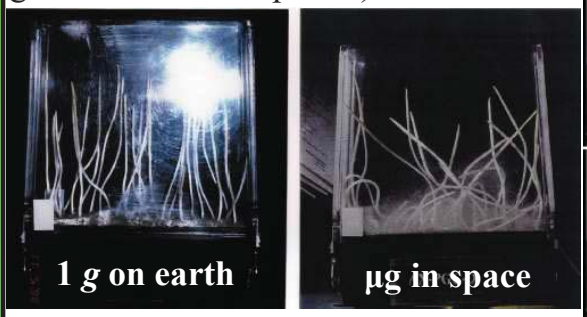
3*) Morohashi K. et al, New Phytol(2017) doi: 10.1111/nph.14689

A study of plant cultivation for space exploration in JAXA

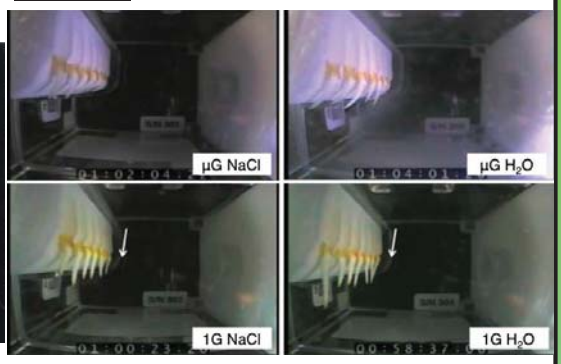
Figure

2. Previous plant experiments under µG at JAXA

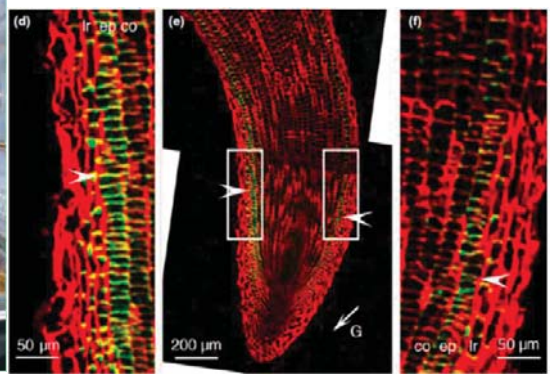
STS-95 space experiment (for plant growth and development) [1*)]



CsPINs [3*)]



Space Seed [2*)]

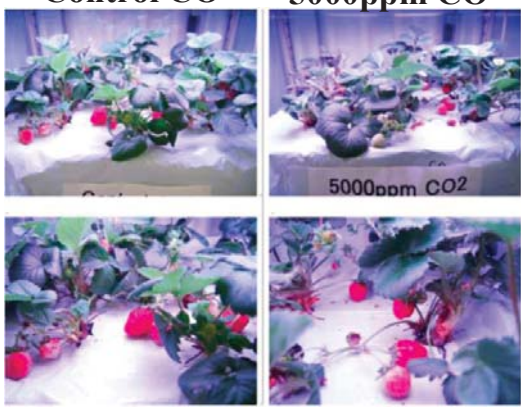


3. The status of the study of plant cultivations in space

3.1 Tests for plant cultivation in a space exploration vehicle

・Effects of high CO_2 level on the plant growth

Control CO^2 **5000ppm CO^2**



・ Growth of the plant on hydro-membrane

Hydroponic culture **Hydro-membrane cultivation**

Condition of roots

A study of plant cultivation for space exploration in JAXA

Figure

3.2. Conceptual study of lunar farming

Commercial production in the plant factory → Food production in lunar farming

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

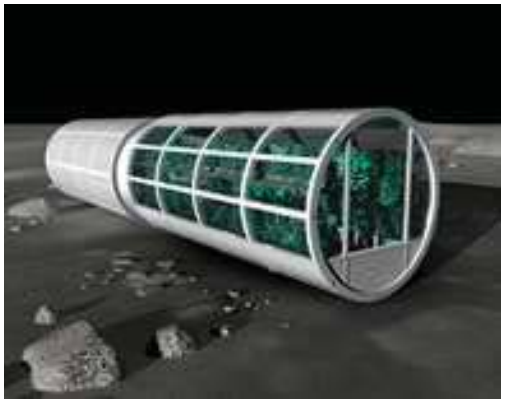


Image of Lunar Farming
(Tentative)

4. Final target of plant cultivation in space