Executive Summary

EDEN ISS

Ground Demonstration of Plant Cultivation Technologies for Safe Food Production in Space

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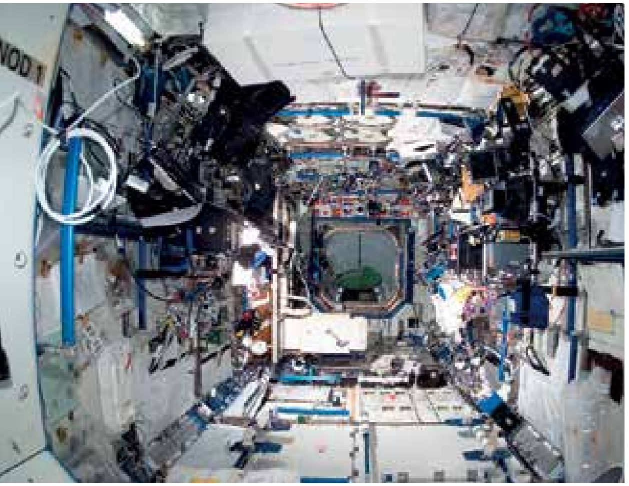

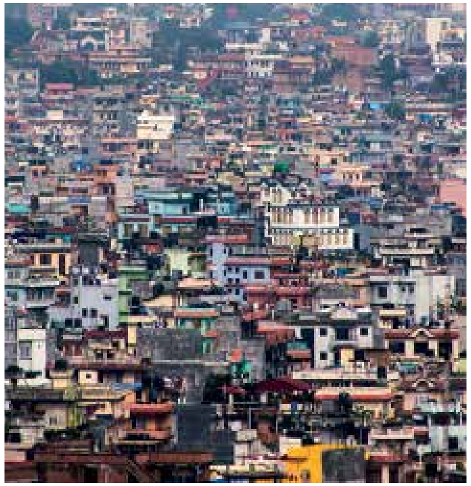

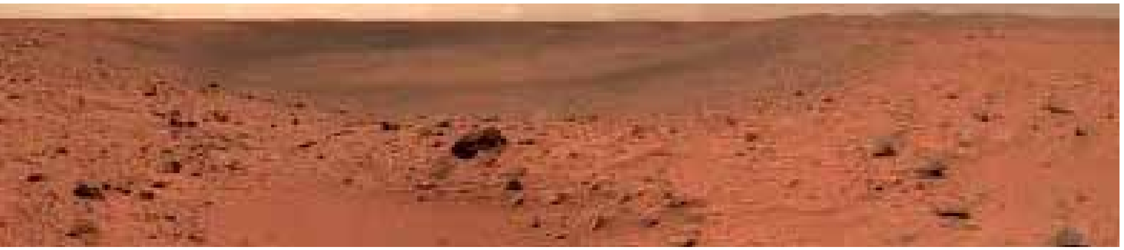

Introduction

Earth

The growing world population will make it increasingly more difficult to ensure that all earth's inhabitants are fed and basic needs are met. Access to fresh grown food is highly variable across the globe and can be restricted by certain factors. Inaccessibility to transportation (and food distribution) networks can present a problem, as well as living in areas that are remote, having a harsh environment, or that have been negatively impacted by consequences of climate change. The dwindling supply of natural resources that are essential for plant cultivation, such as arable land and sufficient water supply, poses another challenge.

Space

At the same time of trying to solve food shortages on earth, researchers, scientists and explorers aim to bring humankind to other planets for long-duration stay, scientific research, and for commercial purposes. Space and extra-planetary surface conditions are extreme environments having qualities similar to the extreme environments on earth; polar areas, desert areas, and areas that have been devastated by natural disasters, humanitarian crises, or political unrest. They all provide a blank starting ground from which food must be cultivated.

Water and air are critical for human survival and do not exist in space. The development of Bio-regenerative Life Support Systems (BLSS), incorporating greenhouses for the production of water and oxygen, is of critical importance to ensure that lives of mission crew members are sustained, while increasing independence from supplies shipped from earth.

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photos: (Antarctica) DLR, 2018; (ISS) courtesy of ESA; (Kathmandu) Sharada Prasad CS/ CC Flickr; (Mars) courtesy of NASA; (landfill) Ashley Felton, 2006; (arid desert) courtesy of pixabay; (moon) courtesy of NASA

Precedents

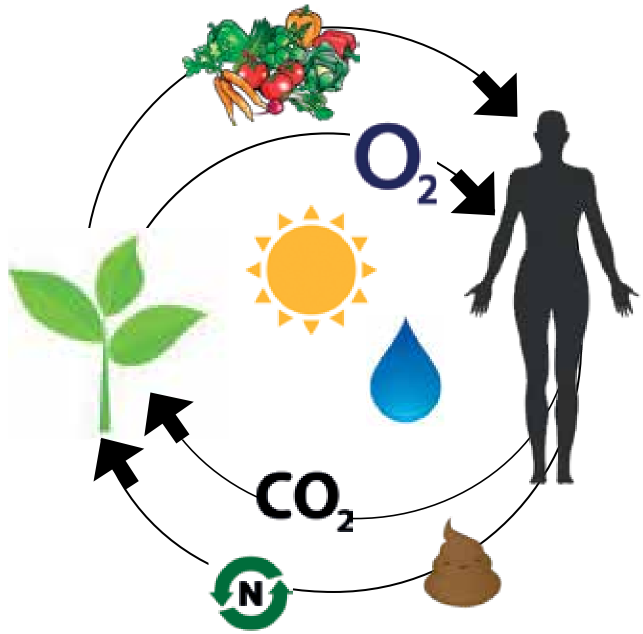
Vertical farming is a growing trend and many vertical greenhouses have been constructed globally, typically in urban settings. They are producing significant amounts of fruits, vegetables, and other consumables, independent from regional conditions, like season, climate, and availability of sunlight. Vertical farming practices have been extremely successful in providing high yields of fruit and vegetable mass, while using 98% less water than used in traditional farming practices in open field agriculture (DLR, White Paper, May 2016). The provision of food directly in the city also reduces transportation costs and associated environmental costs of transporting goods.

Vertical farming is considered a viable solution to the strain and over-working of agricultural land and the large use of natural resources associated with traditional farming practices. Furthermore, arable land is of a finite quantity, and the growing world population would require that productivity per land area would significantly increase. Greenhouses can be optimised using closed-loop systems making resource use more efficient, edible mass more abundant, and crop loss, as it is often attributed to drought, insects and diseases, less common.

In the context of space, the utilization of biological processes to mitigate the physical and psychological obstacles to long-duration human space exploration is considered a high priority. Bio-regenerative life support systems can be developed with a combined focus on the environmental requirements of both plants and humans for survival. Closed-loop systems that consider fully the complimentary nature of resource exchange that occurs between the metabolic processes of both plants and humans are the best way of utilizing available materials and minimizing the production of waste.

Thus far, human space exploration is dependent on resources generated on earth, exemplified by the continuous re-supply missions of food and supplies to the crew onboard the ISS.

The advancement of closed-loop, resource efficient greenhouse technologies can have a great benefit for humankind, both on earth and beyond.



EDEN ISS Aim

The production of food in a closed-loop system using Controlled Environment Agriculture (CEA) technologies can potentially mitigate the problems of natural resource over-utilization and food shortage. Better advanced closed-loop systems can be designed to provide oxygen and water as outputs. CEA technologies are developed for different scales of operation, contexts, and output requirements and aim at optimising the growing conditions and resource use within a closed system for cultivating crops.

EDEN ISS

Project Objective

The objective of project EDEN ISS was to advance greenhouse technologies to make them applicable to space. EDEN ISS developed a testbed greenhouse for the cultivation of high-quality plants for safe food, and validated its subsystems, key technologies, and operational procedures in a mission analogue in Antarctica, an environment relevant to space.

The EDEN ISS mission analogue test campaign took advantage of Antarctica's remoteness and highly isolated conditions, and extreme temperature, and weather conditions for testing the robustness and effectiveness of the greenhouse system.

Project Results

- Advanced knowledge on systems architecture for cultivating plants in closed-loop systems for applications on earth and in space
- Characterisation of the microbial behaviour of cultivated plants in relation to controlled environment parameters
- Advanced knowledge on the psychological impact the consumption of fresh food has on isolated crews
- Advanced knowledge on food quality and safety of vegetables grown in a closed environment greenhouse

The development and implementation of EDEN ISS was a combined effort by 14 international partners. The German Aerospace Centre (DLR) led the project comprised of specialists in concurrent and systems engineering, microbiology, architectural design, human factors, scenario planning, plant biology, food biochemistry, food safety, biological life support, environmental control, greenhouse horticulture, and biotechnology.

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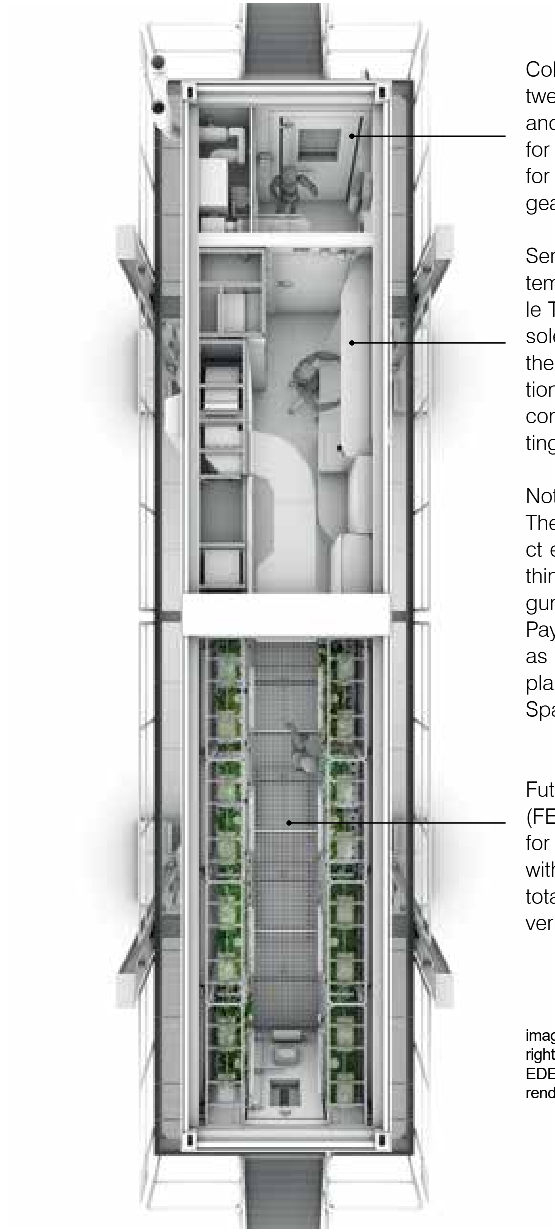

Cold porch - a climatic buffer between the external environment and the service section. It is used for storage and provides space for changing clothes from weather gear to lab clothing.

Service section - contains all systems and subsystems of the Mobile Test Facility (MTF) and the consoles/computers for controlling the entire facility. The service section also serves as laboratory for conducting pre, and post-harvesting procedures.

Note:
The RUCOLA System is an adjunct experiment conducted from within the service section. It is configured as an International Standard Payload Rack (ISPR) and serves as a testbed on earth for growing plants on-board the International Space Station (ISS).

Future Exploration Greenhouse (FEG) – is an insulated container for cultivating plants. It is equipped with eight growing racks holding a total of 42 plant growth trays covering 12.5m^2 of growing space.

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renderings: LSG, 2016

EDEN ISS
Future Exploration Greenhouse & Mobile Test Facility

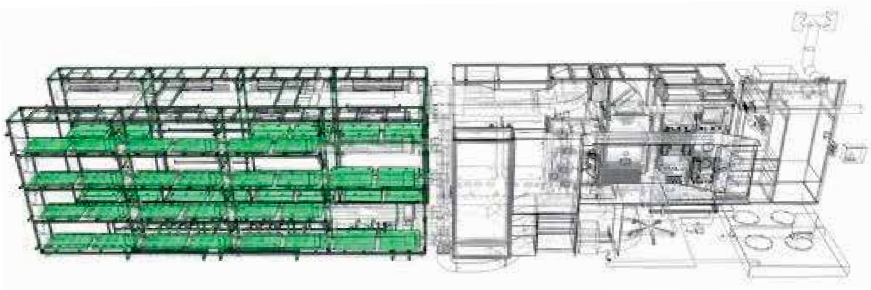
The EDEN ISS Mobile Test Facility (MTF) is comprised of two standard 20-foot shipping containers fitted-out to accommodate a Future Exploration Greenhouse (FEG), a service section, a climatic buffer zone (cold porch), and all the required subsystems for operating a controlled environment agriculture greenhouse.

Implementation

Implementation of the Future Exploration Greenhouse and Mobile Test Facility began in October 2016, when the two customized shipping containers were delivered to the DLR campus in Bremen.

The Assembly, Integration and Test (AIT) phase followed and endured until April 2017, during which time the facility was fully fitted with all hardware and software components.

EDEN ISS Subsystems



Plant cultivation rack

Standardized rack structures span the length of the FEG container on both sides and accommodate the plant growth units. Each rack can accommodate up to four shelves, allowing a variable grow space height of 52cm, 104cm, and/or 208cm. The shelves are fitted with plant growth trays (40cm x 60cm), of food-grade polypropylene, comprised of a protected root zone separated from an open shoot zone by a perforated surface.

Aeroponics is the established irrigation technique for growing plants in the FEG and uses a mist environment, without soil or an aggregate medium, for applying a nutrient enriched water solution to plant roots that are exposed to the open air. The enclosed root zone is fitted with nutrient delivery diffusers, and the exposed growth area is exposed to the LED-powered illumination system.

A separate seed germination unit is dedicated for germinating seeds prior to their transfer to the plant growth trays.

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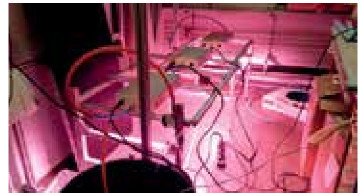
animation still: LSG, 2018; photos: DLR, 2017

LED-powered Illumination System (ILS)

The high-performance LEDs used in EDEN ISS offer a variety of monochromatic light schemes and have a variable light output. The spectral range (wave band) of solar radiation that activates and maintains the process of photosynthesis in plants is emulated using LED lights with the spectral quality of 450, 660, and 735nm, and a broadband white 5700K, resulting in:

- 15% blue (400-500 nm)
- 10% green (500-600 nm)
- 75% red (600-700 nm)
- 2% far-red (700-750 nm)

The LEDs are fabricated as water-cooled box units and are fastened to the plant cultivation rack above each plant growth tray. Seven different light regimes were devised for use in the FEG during the analogue mission in Antarctica based on the height and light requirements of the selected crops that were cultivated. The spectrally-tunable LED lighting system is highly reliable and can be operated remotely. The lighting schedule was designed for a gradual scaling of light intensity in the 'morning hours' to avoid photo-inhibitory shock to the plants passing from zero to full light intensity.



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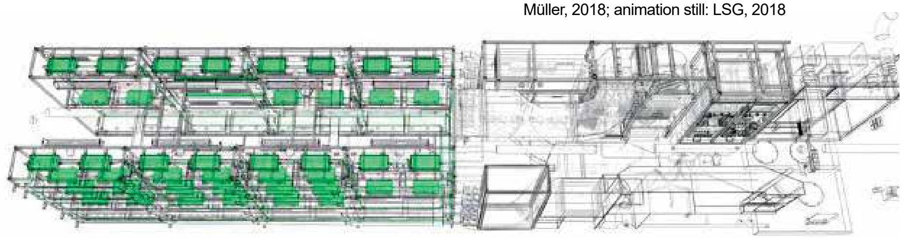


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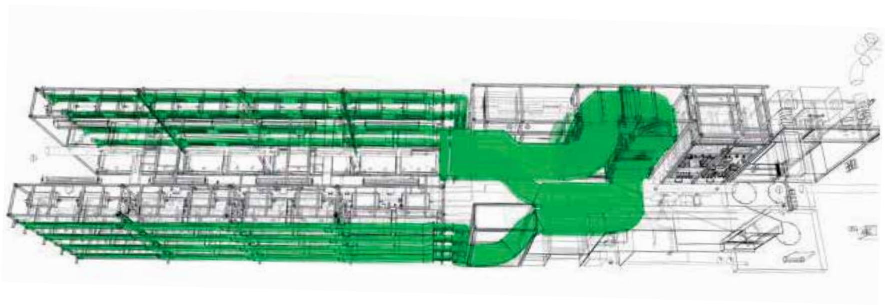

Environmental Control

Atmosphere Management System (AMS)

The Atmosphere Management System manages the atmospheric conditions in the MTF. In the FEG, horizontal ductwork is distributed along the two long, external walls and are fitted with maneuverable louvers. Constant flow valves are installed in each duct to guarantee uniform air distribution.

The control system is used to sensor temperature, relative humidity, CO_2, and O_2. The baseline design for the control system was based largely on crop parameters. The AMS is also used to filter and clean the distributed air by removing volatile organic compounds (VOCs) and dirt.

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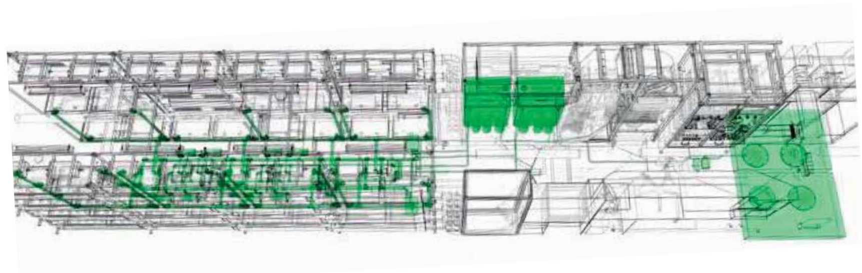
EDEN ISS Consortium
animation still: LSG, 2018; photos: (top) DLR, 2017, (bottom) Bruno Stubenrauch, 2017

Thermal Control System (TCS)

The Thermal Control System provides water-cooling for the Atmosphere Management System (AMS), RUCOLA System, and the LED panels in the FEG plant growth units. Water enters the cooling loops at a pre-defined temperature and is monitored upon its return to ensure sufficient cooling. Waste heat is removed via heat exchangers in each TCS loop. The cooling lines are filled with a water-Tyfocor mixture.



Nutrient Delivery System (NDS)

The NDS is based on soilless cultivation principles where plant roots are exposed to air and are kept moist through a continuous application of nutrients (including nitrogen, potassium, phosphorus, and 11 other mineral elements), and water at the root zone. The efficient aeroponic NDS system enables a better biomass production yield to required water and nutrient ratio.

Two individual bulk nutrient solutions are utilized and can be automatically modified with respect to acid, base, and nutrient salt concentration. The composition of each solution is continuously monitored for electrical conductivity, dissolved oxygen, pH, ion-selective concentrations, and temperature. Solution is delivered by high-pressure pumps to the plant growth trays.

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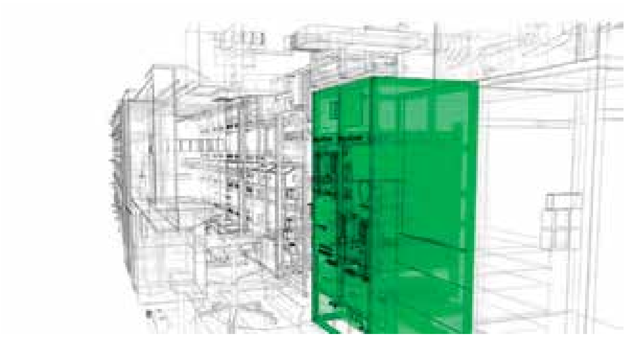
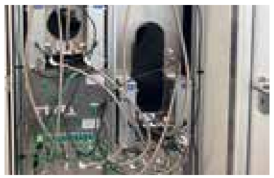
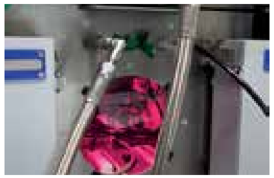


ISPR cultivation system (RUCOLA)

The ISPR cultivation system is contained within the service section and functions independently from the Future Exploration Greenhouse. The RUCOLA System is fitted with its own illumination subsystem, atmosphere management and thermal control subsystems, nutrient delivery subsystem, command and data handling subsystem, and power distribution and control subsystem. The standard payload rack, compatible to ISS standard dimensioning, supports two plant cultivation chambers each operated using different environmental parameters.

The high-fidelity cultivation system with $0.5 m^2$ of production area was developed to advance the Technology Readiness Level (TRL) of plant growth technologies for future (experimental) use on ISS. It is based loosely on its predecessor, the NASA Veggie system, however, surpasses this system with larger available growth surface, taller growth chambers, and longer production cycles through the use of automatic, slow-release application of nutrient and water solutions.





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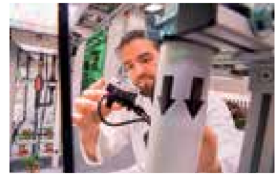
Plant Health Monitoring (PHM) Growth Tray Imagery

The Plant Health Monitoring system in EDEN ISS enables the constant observation of plant growth and health. Using HD cameras distributed throughout the FEG, top view and lateral view images of individual plant trays are automatically captured on a daily basis using automatic image acquisition scheduling. Automatic image processing is used to measure the number of green pixels present in each image. Warnings are given when the number of green pixels decreases from one day to the next, indicating a potential problem and action that should be taken. Harvest time can also be predicted using this algorithm.

Additionally, UF (University of Florida) Imagers are used. They are dual wavelength spectral cameras using a modified GoPro Hero4 commercial camera to sense near infrared. The filters on the camera permit both red and near infrared to be captured, while blocking all greenish yellow, yellow, and orange wavelengths from the image sensor.

Resulting images were interrogated by software using pixel math to produce various differential vegetation indices which were used to record plant growth in real-time, and as markers for comparison purposes to the final harvested product.

Images produced by the UF Imagers during the Antarctic mission were used in EDEN ISS laboratory analyses, as well as being archived in NASA's Life Sciences Data Archive (LSDA), and used for educational and public outreach work.



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Command and Data Handling System

The EDEN ISS Command and Data Handling System is provided by ARGUS, an all-in-one hardware and software platform used for the monitoring and control of all EDEN ISS subsystems. All aquired data on systems operations and control is logged, as well as the daily images captured by the PHM cameras, and is transmitted to the Neumayer Station III (NM-III) for further transmission to international partners.

DLR Mission Control Center

All data is stored in ARGUS and first transferred to NM-III via fiber optic cable. By satellite transmission, data is further transmitted to the Mission Control Center (MCC) at DLR in Bremen for remote mission oversight. Project partners have access to all mission data once it is received in Bremen.

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EDEN ISS Crop Cultivation

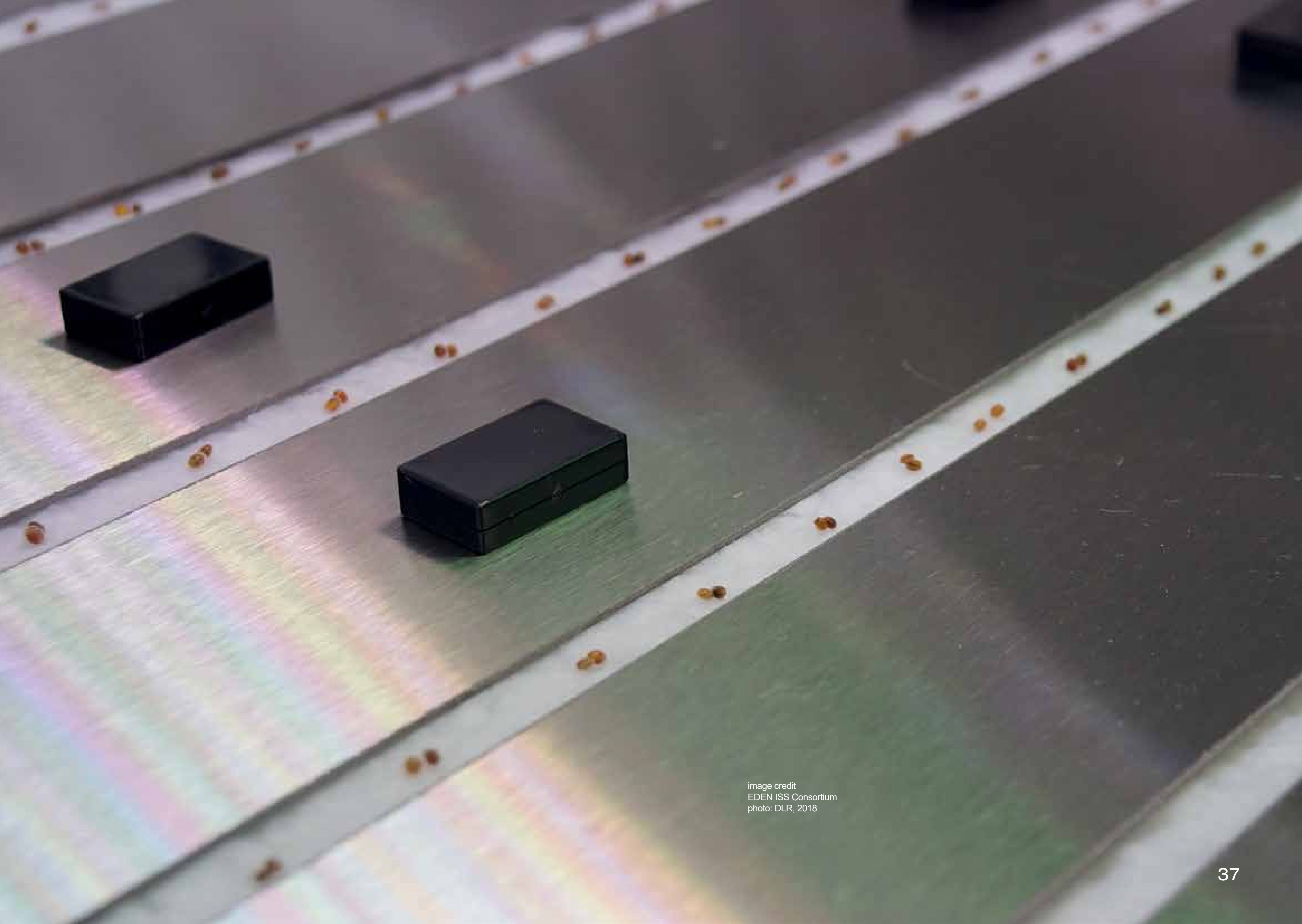
Human health, both mental and physical, is a critical factor in future space missions. Eating food is a fundamental requirement for survival and plays a main role in the maintenance of good health.

In the short term, the provision of fresh food can satisfy expeditioners' craving for fresh food 'with a bite' and can complement or replace the dehydrated foods that are currently consumed. In the long term, the provision of fresh food in space can sustain human explorers, independent from re-supply efforts from earth. In specifying which plants would be cultivated in Antarctica, the psychological well-being of expeditioners was considered.

One of the important outcomes of project EDEN ISS is the demonstration of operation techniques and procedures for the safe production of high-quality food in a semi closed-loop greenhouse configuration.

Aeroponics is the established process for growing plants in the FEG, using a mist environment without the use of soil or an aggregate medium for applying a nutrient enriched water solution to plant roots that are exposed to the open air.

The criteria used for selecting the plant varieties that would be cultivated in the FEG during the testbed mission were based on the central aim of producing a sufficient amount of fresh food at regular intervals. Yield aspects of plants in relation to the time required for a plant to reach maturity (germination to harvest), and the necessary grow space where equally considered.



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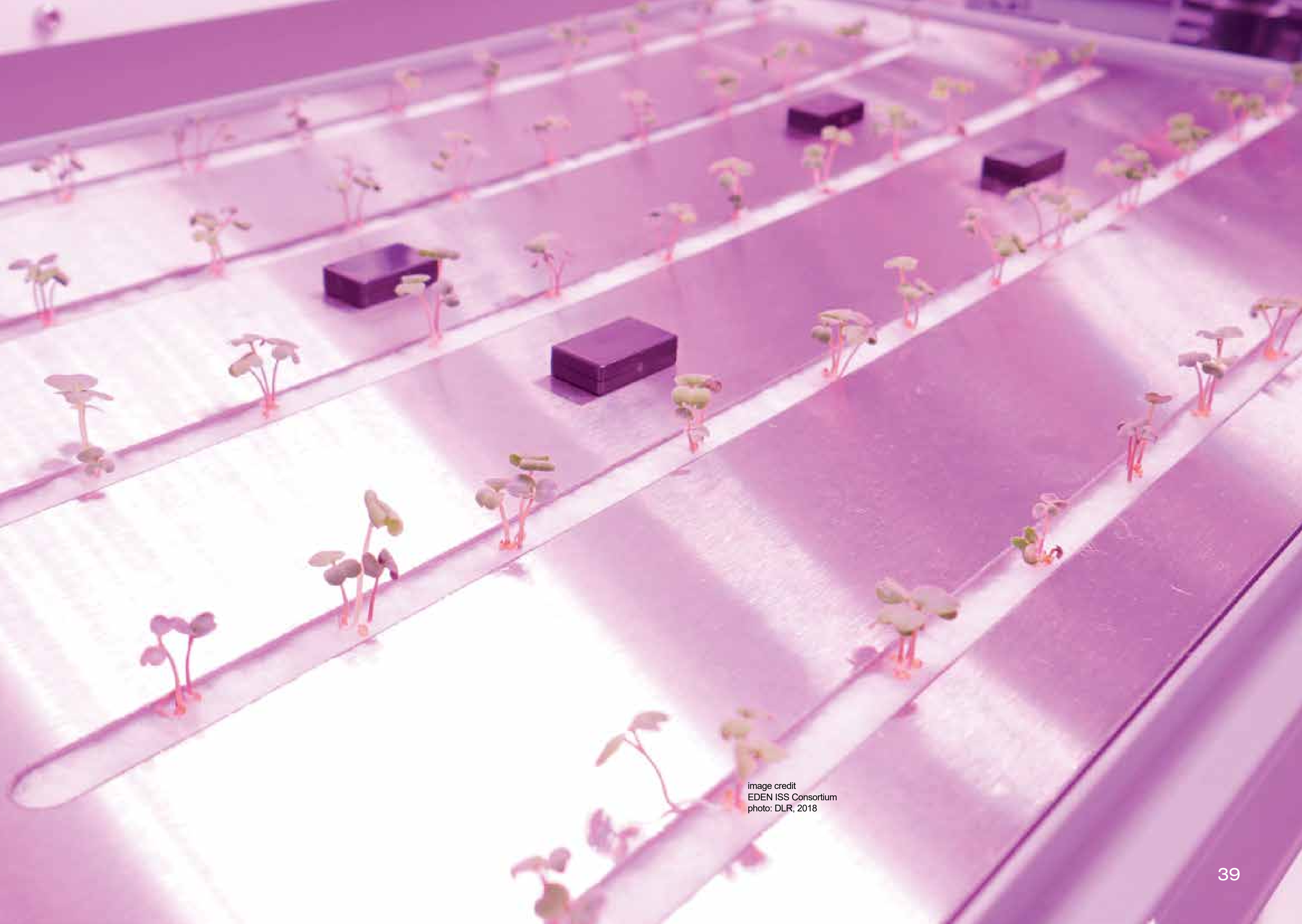

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Aspects regarding the ideal cultivation parameters of individual plants were essential to the final overall selection of crops, with one of the most limiting factors being the single growth environment maintainable by the FEG. An average climate of 21 degrees Celsius and 65% relative humidity was established and suitable crops were determined for this single climatic condition.

Seven individual light regimes based on the optimal light requirements of different plants were devised for the Antarctic mission.

The important production aspects that were investigated for each potential plant variety have included;

- High harvest-index
- Growing conditions (optimal light, temperature, humidity, CO_2)
- Labour requirements (seed treatment, germination, transplantation, pollination, pruning and harvesting). Crops should also be 'ready-to-eat'
- Disease control
- Shelf life
- Human quality aspects – having the greatest physical and physiological benefit for humans in terms of taste, texture, appearance, and pungency

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EDEN ISS Consortium
photos: (bottom center/right) Bruno Stubenrauch, all other photos, DLR, 2017

During the Assembly, Integration and Test (AIT) phase, experiments were conducted by partner institutions to ensure that the final selection of crops to be cultivated in Antarctica were compatible with the growth environment made possible by the integrated technologies in the FEG.

Prior to the test campaign in Antarctica, specification of the most appropriate plants for the testbed were established along with food safety procedures and handling care for each type. Cultivation procedures were defined for each plant variety, including climate, lamp settings, nutrient solution, sowing procedure, crop management, and harvesting for optimal growth and production. The final selection set based on criteria ranking includes:

- (4) varieties of lettuce
- Cucumber
- Dwarf tomato
- Chives
- Tomato
- Strawberry
- Radish
- Parsley
- Spinach
- Swiss chard
- Bell pepper
- Red mustard
- Coriander
- Basil
- Kohlrabi
- Rucola
- Mizuna
- Mint

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Mission: Antarctica

Antarctica is an ideal analogue mission site due to its harsh environmental conditions which mandate the use of robust advanced controlled environment technologies. The extreme cold and arid desert like qualities are comparable to the targeted applications for EDEN ISS such as the moon, Mars, and desolate sites on earth. In addition, the protected and biologically sparse environment of Antarctica dictates the use of a high-fidelity testing environment for conducting microbiological experiments, which is relevant for refining planetary protection protocols for long-duration human habitation of extra-terrestrial planetary-bodies.

NM-III, the German Antarctic research facility, provided accommodations for EDEN ISS personnel during the mission duration. The overwintering team on NM-III consists of 9-10 crew members.

The food produced during the analogue mission provided supplemental nutrition and dietary variation for the over-wintering crew at NM-III. Crew members also participated in EDEN ISS research into the psychological benefit of improved nutrition and access to fresh food during isolation periods.

Transport

In October 2017, the EDEN ISS Mobile Test Facility began its maiden voyage. From Bremen, Germany the facility was transported by truck to Hamburg and loaded onto the cargo ship, the Golden Karoo, for shipment to Cape Town, South Africa. In Cape Town, the facility was transferred to the S.A. Agulhas II which delivered it to the Antarctic continent on the third of January, 2018. The facility was unloaded at sea ice edge, and from this location conveyed by pistonbully vehicles to the mission site.

The containers were positioned on a stationary platform roughly 400m from NM-III and a large power cable and fiber optic cable were extended from the station to EDEN ISS. The Power Distribution System (PDS) is a stabilized 230 VAC power supply and provides power to all elements in the MTF requiring electricity.

EDEN ISS personnel arrived by plane to the logistics hub at the Novo Airbase in Antarctica and from there were transferred to NM-III.

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Internal subsystem integration followed and a thorough cleaning of the facility was performed using TransMADD, a vaporizer for sanitation. In February 2018, the first plants were inserted into the Future Exploration Greenhouse.

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Crop Cultivation Experiments

February 7, 2018 marks the start of nominal operations of the greenhouse with the first sowing of tomato, pepper and cucumber. Paul Zabel, trained specialist from DLR, oversaw all mission operations in Antarctica. His responsibilities included maintaining the EDEN ISS systems, growing and harvesting the vegetables, and conducting the programmed research. Regular activities in the greenhouse continued until 20. November.

Growing Procedure

Sowing and Germination – rock wool blocks are inserted into a pre-fabricated plastic tray. The blocks are saturated with nutrient solution and seeds are embedded loosely within. The rock wool is kept moist during the germination phase which lasts approximately 10-14 days.

Transplantation – once roots have grown through the rock wool block, the entire piece is transferred to the plant growth trays.

Pollination - almost all crops grown naturally utilize wind pollination. Manual pollination (e.g. with a Q-tip) was performed on the strawberry plants.

Pruning – most crops require the removal of surplus side shoots or other plant material in order to produce an optimal output.

Plant care - regular monitoring, checking for abnormal appearance (e.g. necrotic spots on leaves, wilting of plants). Critical importance lies in the early detection of plant disease so proper measures can be taken immediately to fix the problem; this was monitored by onsite personnel and remotely by international consortium partners.

Harvesting – handling of edible biomass observing proper clipping location for fruits and vegetables of maturity; different plants have different maturity aspects including:

- growth size measured by dimensions and/or weight
- duration time for normal cultivation of the given variety, under given growth parameters within the FEG

Plant samples for further analysis after the mission campaign were also collected and preserved by freeze-drying them or keeping them at a minimum of -40°C.

Prior to consuming the cultivated vegetables, a number of safety procedures are executed on a small sample of the harvest. Using the prescribed EDEN ISS procedures, on-site safety analysis can monitor and/or detect:

- Common pathogens
- Total microbial count
- Yeasts and moulds
- Total coliform
- *Salmonelle spp.*
- *Enterococcus spp.*
- *Pseudomonas aeruginosa*

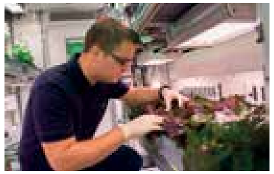
Monitoring Procedures

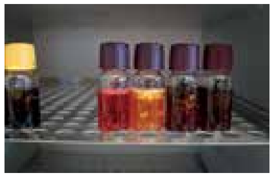
The quality of cultivated food is partially determined by the level and type of the microbial loads that they carry. Microbial contamination by fungi or bacteria can affect all materials and is a safety danger, particularly on long-term missions (e.g. ISS).

EDEN ISS uses the gas-analyzing instrument E-Nose for real-time detection of the microbial loads present on the cultivated plants, and on surface locations within the FEG.

The E-Nose is an electronic sensor for detecting chemical off-gassing signatures of pathogens such as *E. coli* and *Salmonella spp.* and is used to monitor plant health prior to human consumption.





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In addition to the E-Nose, other on-site quality analysis tools and procedures were implemented by on-site team member Paul Zabel for the purpose of ensuring food quality:

Refractometer - measures the percent of Total Soluble Solids (TSS) in a given weight of plant juice, including the amount of sucrose, fructose, vitamins, minerals, amino acids, proteins, and hormones.

Penetrometer - measures the firmness of relatively homogenous fruit and/or vegetables.

Colorimeter - measures the color coordinates of food samples as an indication of their bioactive content.

Chlorophyll meter – measures the level of chlorophyll concentration in leaves, an indicator of plant health.

Nitrate Ion meter - evaluates the nitrate concentration in harvested samples. The consumption of high levels of nitrate can cause serious health hazards.

Organoleptic survey – performed on-site with hedonic acceptability scale; crew assessments on aroma, appearance, texture and taste, scored between 1 and 9.



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Decontamination

TransMADD (Transportable Modular Aerosol based Decontamination & Disinfection System) is an aerosol-based decontamination and disinfection system for sterilizing enclosed volumes, hard to reach places, and cavities where potential pathogens harmful to both plant and human health may reside. The TransMADD system is used when pathogens are detected by E-Nose and/or by swab culture.


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Project Validation

Sample Return Mission

The duration of the EDEN ISS mission spanned nearly a year, with no possibility for a sample return to home laboratories until the end of the mission.

Stabilization of the cultivated crops was therefore essential to enable further testing at the laboratories of relevant project partners. Procedure for their preservation was freezing at low temperature of -40°C or less immediately after harvesting, or freeze-drying the samples and storing at room temperature.

The samples collected from the FEG for post-mission sample analysis and data processing by home laboratories arrived in Europe in December 2018 in the same state as they were stored in Antarctica.

image credit
EDEN ISS Consortium
photo: DLR, 2018

System and component validation

Throughout the analogue mission, EDEN ISS controlled environment agriculture (CEA) technologies and subsystems were tested under extreme conditions, offering real knowledge on the robustness of the designed greenhouse system. During the mission analogue, the following were determined:

- the maintenance demand of each subsystem
- which components failed under operation parameters and spare-part replacement
- the electrical energy demand of each subsystem
- the required crew time to maintain each subsystem

The ISPR RUCOLA system was returned to Europe for further testing on the hardware that was developed and in operation during the test campaign in Antarctica. The RUCOLA system will be developed further to achieve the goal of installing it on-board the International Space Station (ISS).

Operation procedures validation

Operation procedures are indispensable sets of instructions used by astronauts for conducting complex tasks. For the first time within project EDEN ISS, a set of operation procedures for handling systems and scientific equipment for a future space greenhouse was developed. The procedures were tested in Antarctica, focusing largely on plant cultivation. On-site operator Paul Zabel reviewed and rated the given procedures based on his experience of using them after the mission analogue was complete. A final set of operation procedures is an outcome of the project and a good starting point for future plant cultivation in space projects.

Plant cultivation experiments

The production of edible plants using controlled environment agriculture technologies was measured in fresh weight per m^2. Within the $12.5m^2$ of greenhouse growth area, 270kg of fresh vegetables were produced during a 9-month timeframe, 7. February - 20. November 2018.

Food quality and safety assessment

To evaluate the microflora composition of different vegetables an experimental test plan for measuring the qualitative, quantitative, and organoleptic qualities of all plant tissue samples in three core areas; food quality, food safety, and storage was devised.

The overall quality and safety of food was assessed through a combination of tests including;

- Sampling
- Optical measurement of plant pigments
  to measure chlorophyll a, chlorophyll b and total carotenoids of the cultivated plants using the spectrophotometric measurement process.
- FRAP, TPOLY & TF assays
- Folin-Ciocalteu total polyphenol assay
- Total anthocyanins determination
- Flavonoid analysis
- Total glucosinolates determination
- Non-structural carbohydrate (glucose, fructose sucrose) and starch quantification
- Structural carbohydrate fiber characterization
- Isoflavonoid analysis
- Polyphenol analysis
- Ascorbic acid analysis
- ß-carotene analysis
- Organic acid and inorganic anions analysis
- Microbial analysis
- Organoleptic analysis
  to measure human response to the composition of food and drink in relation to appearance, odour, texture, and taste.
  Prior to the test campaign in Antarctica, a trained sensory panel (Food@LIT sensory panel) provided objective feedback on the crops produced during the pre-Antarctic, AIT phase. For the Antarctic mission, the crew at NM-III was trained in sensory evaluation and in quantitative description analysis.



image credit
EDEN ISS Consortium
all photos: automatic imaging of plant growth trays in FEG, 2018



image credit
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photo: DLR, 2018

image credit
photo: Hanno Müller, 2018

Further research supporting EDEN ISS goals can include:

- Improvement of environmental parameters for increased biomass production
- Testing of new plant cultivars
- Improvement of operation and handling procedures for cultivating crops in a closed greenhouse environment (crew time for maintaining the facility can be considered a research priority)
- Improvement of the remote-control operation of the greenhouse (Mission Control at DLR Bremen oversees all operations in Antarctica, enabled by the ARGUS system housed in the service section of the Mobile Test Facility)
- Increasing knowledge on microbial contamination in closed greenhouse environments
- Optimization of energy use by combined system
- Further investigation into the positive impact fresh food has on mission crew members

For the winter of 2020, external researchers are invited to propose experiments to be conducted at EDEN ISS in Antarctica.

Future Applications
EDEN ISS DELTA-Mission

A collaboration between DLR and Alfred Wegener Institute (AWI) will keep the MTF in Antarctica for a minimum of two additional years, thus enabling 2 more isolation phases, open for exploitation by international research teams.

In January 2019, experienced personnel from the EDEN ISS team travelled to the mission site for comprehensive cleaning and part-replacement of the MTF. In total, over 60 different replacements, repairs and/or enhancements were performed, including;

- Switch-out of observation cams, replaced with higher resolution cameras
- Replacement of ARGUS sensors for greater accuracy
- Addition of fans inside the FEG and service section
- Upgrade made to the AMS system with additional heating elements
- Repair of the thermal system, specifically the outside cooling fans
- Implementation of new rockwool holders for the aeroponic system
- Refilling of supplies and consumables
- Installation of a dehumidifier system in the service section

The MTF stays in sleep mode, already pre-outfitted with seeds, until mid-May 2019 when the facility will be re-activated remotely from the Mission Control Center in Bremen. Three dedicated members of the NM-III team will oversee seeding, harvesting, and cleaning within the facility. All other operations, such as monitoring and environmental control will be performed remotely through Mission Control at DLR.

The technologies that EDEN ISS develops for space missions can also be used on earth. Knowledge generated by the project will help earth-based greenhouse systems to optimize plant-environment interactions, increase biomass production at lower cost, and improve the quality of food that is cultivated.

Solutions developed within the project could also support a reduction in pesticide use in closed environment agriculture. Positive changes to food growth on earth can have a global impact and help in fighting against malnutrition and environmentally damaging farming practices.

Spin-offs

DLR in Bremen is investigating the implementation possibilities for CEA technologies in the arid regions of Egypt and Morocco.

In the bilateral projects, DLR develops a preliminary design for a closed-loop CEA greenhouse. Both projects are funded by the BMBF (Bundesministerium für Bildung und Forschung) in Germany, and by the Science & Technology Development Fund (STDF) in Egypt, and the Moroccan Ministry of Science (MESRSFC) in Morocco, respectively.

In Egypt, partnership is made with the Egyptian National Research Center (NRC) in developing project goals; and with the University Ibn Tofail (UIT) in Morocco. The Desertec University Network (DUN) of Germany lends their expertise in both projects. The projects aim to establish a network for future collaborative efforts aimed at building and testing a greenhouse system in the MENA region.

Adaptations towards Future Exploration

The Future Exploration Greenhouse developed in project EDEN ISS, and tested in Antarctica, provided key findings in regard to system performance, crop yield, crew acceptance, and contamination for the design of a future greenhouse for lunar and Martian applications. Recommendations for a greenhouse facility for applications to long-duration space missions are based on mass, power, volume, reliability, and serviceability and are an outcome of the EDEN ISS project.

image credit
EDEN ISS Consortium
rendering: LSG, 2019

Project Coordinator

German Aerospace Center (DLR), Germany

Institute of Space Systems (DLR-RY) Bremen

The Institute of Space Systems investigates and evaluates complex astronautic systems in the context of space research. DLR-RY has competency in Concurrent and Systems Engineering and uses them to develop Controlled Environmental Agriculture (CEA) technologies and their implementation in extra-terrestrial greenhouses and closed-loop habitation.

DLR-RY was the project coordinator of EDEN ISS and responsible for various work activities including the execution of the science activities in Antarctica.

Institute of Aerospace Medicine (DLR-ME), Cologne

The Institute of Aerospace Medicine deals specifically with life sciences as they apply to space flight, exploration, aviation, and traffic. Projects focus on the viability and adaptability of living things to extreme environmental conditions on earth, or as they occur in space.

DLR-ME provided expert knowledge in microbiology and supervised the microbial investigations during the test campaign in Antarctica, focusing largely on the properties of greenhouse cultivated food and its effect on crew members. Further, it investigated the psychological impact of fresh produce on the isolated group in Antarctica.

LIQUIFER Systems Group GmbH (LSG), Vienna, Austria

LSG is a multidisciplinary task force comprised of a wide range of experts from the fields of systems architecture and engineering, robotics, human factors and science. LSG's project expertise focuses on space exploration prototypes, analogue simulation structures and scenarios, human factors, and habitability.

LIQUIFER was the coordinator of systems requirements and interfaces, and coordinated all activities regarding outreach and dissemination. Further, LIQUIFER designed and built the workspace of the Service Section and was instrumental in the design of EDEN ISS greenhouse concept developed for moon and Mars.

National Research Council (CNR), Italy

Institute of Agro-environmental and Forest Biology (IBAF), Porano / Monterotondo / Legnaro / Naples

The general research fields of IBAF are plant-environment interactions, including the biological and evolutionary processes and mechanisms in plants as they occur in relation to their environment, and the control of plant physiology and biochemistry for food and biomass production. The research group has experience on space-related plant biology considering controlled environment plant growth. The IBAF characterizes the key metabolites in the food and biomass produced by the EDEN ISS project, including carbohydrates, organic acids, sugar alcohols, amino acids, and mineral ions.

Institute of Food Science (ISA), Avellino

ISA researches the enhancement and technological transfer of food quality and its effect on human health. The ISA research group has extensive experience in food biochemistry and microbiology, food safety, and in the study of natural extracts used as antimicrobial products for health and agronomy. Through use of recent analytical approaches such as UPLC-DAD, the group is extensively involved in the qualitative and quantitative evaluation of secondary metabolites.

University of Guelph, Canada

Controlled Environment Systems Research Facility (CESRF), Guelph

The CESRF at the University of Guelph, began as a Natural Sciences and Engineering Research Council Collaborative Research and Development funded project (NSERC-CRD) in collaboration with the aerospace and greenhouse sectors. It has since evolved into a research program that has state-of-the-art capacity in controlled environment studies and those related to biological life support for space exploration. The CESRF was responsible for the integration of the nutrient delivery system of the EDEN ISS greenhouse facility, and contributed to the power control, command, and data handling subsystems.

Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany

AWI is one of the worlds' leading polar research organizations and delivers significant contributions to international research on climate, marine, and coastal issues. AWI is the national manager and implementation agency of the National German Arctic and Antarctic Programme.

The Neumayer III Station operated by AWI has provided the logistic infrastructure for the EDEN ISS team and has accommodated at their facilities EDEN ISS project personnel during the test campaign in Antarctica.

Enginsoft S.p.A., Trento, Italy

EnginSoft is a consulting company specialized in scientific IT targeted at the optimization of design and production processes. Operating in the field of Computer-Aided Engineering (CAE), EnginSoft provides services in virtual prototyping, advanced simulation, and in Process Integration and Design Optimization (PIDO). Simulations include; mechanics, fluid-dynamics, fast dynamics and crash, metallurgy, process simulation, environmental engineering, off-shore engineering, acoustic analysis, and more.

EnginSoft was responsible for the study of Thermal Fluid Dynamics of the facility and has provided detailed Computational Fluid Dynamics simulations of the environmental control.

Airbus Defence and Space, Friedrichshafen, Germany

Airbus Defence and Space is a large, international company employing over 17,000 men and women with locations in France, Germany, the UK, Spain, and the Netherlands. Airbus is a committed leader in space transportation, and in satellite systems and services. Airbus has expertise in the development of automated, alternative space greenhouse concepts, with a focus on the analysis of biochemical parameters, and the positive identification of biological contamination on surfaces, and of air borne contamination.

Airbus was responsible for the monitoring of plant health and contributes to advancing the plant growth chamber design towards compatibility with the International Space Station (ISS).

Thales Alenia Space Italia S.p.A. (TAS), Torino, Italy

TAS Italia has more than 40 years of experience in the design, integration, testing, operation, and commissioning of innovative space systems. The satellites and payloads designed by TAS Italia set the global standard for space systems that provide communications and navigation services, monitor our environment and the oceans, help us better understand climate change, and drive scientific progress.

TAS Italia is responsible for the environmental control of EDEN ISS, specifically for the two ISPR plant cultivation systems. TAS Italia oversees the advancement of the RUCOLA plant growth chamber design towards application on-board the ISS.

Arescosmo S.p.A., Aprilia, Italy

Arescosmo's mission is to supply products and services dedicated to support life and survival of defense and security forces, as well as to develop systems for space missions and applications, based on the best and most consolidated mechanical technology, software, textiles, and innovative materials.

Arescosmo has aided in the design of the facility and has built the service section of the mobile test facility with a focus on environmental controls. Arescosmo coordinates the post-demonstration design and contributes to the study on evolving the greenhouse module design towards deployment on the moon or Mars.

Wageningen University and Research, Netherlands

Wageningen UR Greenhouse Horticulture of the Dutch Foundation for Agricultural Research (SDLO), Wageningen

The SDLO is a university research program comprised of undergraduate, graduate and post-doctoral students, and staff dedicated solely to greenhouse horticulture. SDLO is committed to making long-lasting contributions to sustainable and competitive greenhouse horticulture, with concentrated effort on the development and testing of new transparent materials, and on sensor and control technology.

Wageningen University and Research was responsible for plant analysis and has developed the operation procedures for EDEN ISS. The foundation also provided investigations for the terrestrial applications for the systems and technologies developed in the project.

Heliospectra AB, Göteborg, Sweden

Heliospectra is a Swedish-based SME specialized in smart LED lighting for plant science and horticulture applications. The overall mission of the company is to create light systems that optimize and automate the light environment to provide more ecological, effective, and economical methods for the cultivation of plants. The company is a manufacturer of several types of “intelligent” multi-waveband LED luminaries.

Heliospectra was responsible for the EDEN ISS lighting system and helps to identify terrestrial applications for the project.

Limerick Institute of Technology, Limerick, Ireland

The Institute’s flagship research centre ‘Shannon Applied Biotechnology Centre’ (Shannon ABC) explores natural and novel bio-active substances of value, including those derived from waste streams and marine, plant, animal, mammalian, and microbial sources. Shannon ABC focuses on the development, enhancement, and commercialization of biotechnology for market competitiveness, and offers expertise in bio-processing, extraction, purification, and screening of derivatives derived from natural products and waste streams.

Limerick has provided the supervision of food quality, safety, and processing during the test campaign in Antarctica.

Telespazio S.p.A., Rome, Italy

Telespazio Naples (hosting MARS Centre) was established in 1989 and has flown a number of scientific payloads in microgravity through the exploitation of several platforms, including parabolic flight aircrafts, sounding rockets, the Russian Foton Space Capsule, and the U.S. Space Shuttle. Telespazio Naples was commissioned by ESA to implement the Facility Responsible Centre (FRC), enabling the interaction among the onboard Experiment Procedures (EPs), the FRC ground team, and the science team located at their User Home Basis (UHB).

Telespazio’s main responsibility in EDEN ISS was the definition of operation procedures leading up to the test campaign in Antarctica and the supervision and validation of these procedures via remote operations during the test period.

University of Florida (UF), USA

Department of Horticulture Sciences and Interdisciplinary Center for Biotechnology Research, Gainsville, Florida

The UF Space Plants Lab brings together expertise in molecular biology, biological imaging, and biotechnology to explore plant responses in spaceflight environments and planetary habitation analogs. The team has launched multiple spaceflight experiments and has conducted experiments in extreme terrestrial settings to evaluate the physiological adaptation of plants to the novel environments of space exploration. The team is primarily supported by competitive grants from the NASA Division of Space Life and Physical Sciences Research and Applications.

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EDEN ISS Consortium
photo: 2018

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