Space Food: A taste of the future

Dr. Natalie Leys
Space travel - not a healthy journey ...

Cosmic radiation, Weigtlessness, Psychological stress, ...

Kidney function ↓ + Ca\(^{2+}\) ↑ = kidney stone risk ↑

Cardiovascular changes (swollen face + thin legs)

Stress response ↑

Radiation damage & cancer & cataract risk ↑

Bone Loss

Changes in human microbiome

Healthy food for healthy body

Muscle Atrophy

Food taste and digestion ↓

Dysregulated Immune response ↓

Distrubance of motion senses = Motion sickness

Belgian Astronaut Frank De Winne in ISS
Extreme body stress requiring adequate nutrition

Taste changes

Digestion changes

Eating in space is a tricky thing, even bread crumbs are potentially dangerous.

‘Eating’ ‘together’ is essential for mental & social health

Healthy food for healthy body

SUPPLIES!

Stuck in a ‘camp’ for months, not able to go to the grocery store.

All that you have to survive on is stowed in the ‘backpack’ you took

The items in this ‘backpack’ have been predetermined long ahead of time.

No (Limited) fresh food, only items that stay good for weeks without requiring processing or refrigeration: dried or canned (or frozen).
“CAMPING”

Fully dependent on Earth supply
For future mission: grow fresh food in space
FROM CAMPING TO SETTLEMENT

Space Farming
AgroSpace
Moon Gardens
...

EDEN ISS — Greenhouse for ISS, moon and Mars
WHAT ABOUT

Could the “sea environment” be promoted as floating test platform for space farming & soil free farming, …?

What about floating research (& ecotourism) ‘Ocean Stations’ / ‘Ocean cities’ at fixed location?

Could the maritime sector benefit from more sustainable solutions for living at sea through such gardens, greenhouses, life support systems, onboard ships, platforms, …’ ?
Underwater farming in “balloon gardens” (Italy)

Could the maritime sector find a connection to these new agriculture initiatives?

‘Ocean farming’
For future mission:
grow fresh food in space

FROM CAMPING TO SETTLEMENT

Space Farming
AgroSpace
Moon Gardens
...

This does not work without fertilizers ...
Sustainable

= closing the loop!

BIOREGENERATIVE

planting potatoes in a ‘Martian’ greenhouse using Martian soil and his own ‘metabolic waste’.
Max Mergeay (SCK•CEN)  
1 of the 4 ‘fathers’  
of MELiSSA  

Since 1989
In situ resources

Waste liquefaction

Carbon transformation

Nitrogen transformation

Food & water & oxygen production

SOIL FREE WATER-BASED

VEGAN

MELiSSA loop concept

1 - Waste liquefaction

2 - Carbon transformation

3 - Nitrogen transformation

4 - Food & water & oxygen production

Crew

Water

CO₂

NO₃⁻

O₂

CO₂

Urine

Minerals

NH₄⁺

Volatile Fatty Acids

Minerals

NH₄⁺

http://www.esa.int/Our_Activities/Space_Engineering_Technology/Melissa

https://en.wikipedia.org/wiki/MELiSSA

+E In situ resources

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‘MELISSA community’
14 european Members & many contributors
The concept, inspired of an ecosystem
The challenges are big

Dissecting the earth ecosystem to its essential components & understand how they work

Then putting them back together, but smaller, with less complexity, less buffers or back-ups, …

Nevertheless predictable & reliable
Engineered to targeting maximum yield

Using biotechnology which can be functional in space conditions (launch & radiation & microgravity)

A mineaturised sustainable synthetic earth ecosystem transplantable to space
The world of MELiSSA ...

MELiSSA team at work

MELiSSA team ... after work
The ESA MELiSSA pilot plant @ UAB, Barcelona, Spain
How about waste & water treatment onboard ships?

Environmental impact? Could it benefit of Closed loop regenerative systems?

Biodiversity impact & biological monitoring & sanitation of ballast water?
The primary decomposers

The primary biosynthesizes

→ single-cell proteins, vitamins, ...!
Food & oxygen production in space with cyanobacteria

Arthrospira

- Also known as Spirulina
- Blue-green filamentous cyanobacteria
- Lives in warm alkaline salty lake water, water rich in carbonates, at pH 9 & 35°C
- Cylindrical cells, in helicoidale strings, called ‘trichomes’ or filaments
- Continuous illumination, no need for dark
- High cell density Bioreactor cultivation

In SPACE - life support system - MELiSSA

PHOTOSYNTHESIS

- Nitrate removal from waste water
- CO₂ removal from the air
- O₂ Production of from water,
- Edible biomass production
**Arthrospira – food supplement**

- **Edible**
  - Consumption by Aztecs, documented since 1500
  - Still used by several tribes in Africa
  - In Europe known as ‘super food’ – Spirulina

- **Highly interesting Food value**
  - Thin cell wall, full organism digestible, no need for processing or cooking, no waste (↔ algae, plant)
  - Single cell protein source, Low DNA/protein-content (↔ other bacteria, algae, plant)
  - Does not contain phyco-toxines (↔ other cyanobacteria)
  - Rich in essential fatty acids
  - Contains vitamins, minerals, antioxidants
Bio-engineering – *Arthrospira* in photo-bioreactor

High efficiency
Predictive control
Biomass quality
Does this also work in space?
Cosmic radiation in space → Biological impact?

Type of Radiation in space different than on earth
- Electrons, protons, helium nuclei, heavier nuclei, neutrons, photons, muons, pions, ...
- Up to extremely high energies around $10^{12}$ MeV
- Strong dependence on location, solar cycle and shielding

Dose rates in space higher than on earth
- On Earth ~ 0.1 μSv/h
- On ISS (LEO) ~ 25 μSv/h $\times 250$
- On the way to mars ~ 75 μSv/h
- On surface of mars ~ 25 μSv/h
Reduced gravity in space → Biological impact?

<table>
<thead>
<tr>
<th>Earth</th>
<th>Space</th>
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<tbody>
<tr>
<td>Sedimentation, Convection, Diffusion</td>
<td>Diffusion only → Fluid quiescence, ‘low shear’</td>
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e.g. boiling water in space

different solid/liquid/gas fluid dynamics
ArtEMISS project

“First bioreactor with cyanobacteria in space”

For controlled microbial oxygen and food production in space

- Investigating
  - Oxygen production
  - Biomass production
  - Biochemical composition (nutritive value)

- In a controlled photo-bioreactor,
  - axenic (1 strain),
  - batch & continuous,
  - defined continuous illumination (no day/night),
  - Fixed temperature and
  - synthetic waste water

- Under spaceflight conditions: gravity, radiation, magnetism...
‘Bio-reactors’ in space require ‘space technology’

ArtEMISS hardware - ‘mini photo-bioreactor suitable for space’

20cm 50 ml culture chamber
‘Space bioreactor’ - intensive ‘training and testing’

ArtEMISS hardware - ‘mini photobioreactor suitable for space’

- Light characterization
- Material Bio toxicity
- Sterility throughout assembly & operation
- Mixing, Flocculation, Biofilm
- Gas removal
- Etc.
...
ArtEMISS flight hardware - ‘mini Arthospira photobioreactor for flight’
Running Bioreactor in space  = success!

- First time mini photobioreactor built, certified and running in space.
- First long-term (> 1 month) culture of an axcenic edible photosynthetic organism in ISS (in space?)
- First time life data feedback of bioreactor from space, and ground commanding
- Ground breaking research, enabling a full portfolio of future biotechnology applications in space
Oxygen production in the space bioreactor

7 days batch
4x 7 days batch
contineous

Arthrospira sp.

Oxygen production follow-up through pressure measurements

inoculum OD750=1,037
pH= 10.40
pH zarrouk: 9.51

sample res. OD750= 0.617
OD770= 0.578
pH= 10.46
ODzarroukres: 0.578
pH: 10.17
Waiting for sample return (space X 14)
Development of molecular analysis tools for the space micro-organisms

DNA → messenger RNA → protein → metabolite

gene stability → gene expression → protein expression → Metabolite production

genomics → transcriptomics → proteomics → metabolomics

C4 - *Arthrospira*

Microarrays, RNA seq, ...

High-throughput Technologies

On small sample volumes
Astronauts can use Spirulina as part of their low-weight, low-waste, high-nutrient diet during space flights.
A list of the micro-organisms used for SCP production

**Fungi**
- *Aspergillus fumigatus*
- *Aspergillus niger*
- *Rhizopus cyclopium*

**Yeast**
- *Saccharomyces cerevisiae*
- *Candida tropicalis*
- *Candida utilis*

**Algae**
- *Spirulina sps.*
- *Chlorella pyrenoidosa*
- *Chondrus crispus*

**Bacteria**
- *Pseudomonas fluroescens*
- *Lactobacillus*
- *Bacillus megaterium*
Oceans & Sees & Lakes

An endless source of
microbial diversity

&

Novel ‘NATURAL’ ‘renewable’ microbial foods &
Novel Nutricuuetical potential :

Single-cell proteins, vitamins, ...
Biodiversity is globally recognised as the cornerstone of healthy ecosystems.

It forms the basis for all ‘services’ produced by nature.

These so-called ‘ecosystem services’ provide us with food and medicine, provide the raw materials needed for economic activity and innovation, allow a whole range of leisure activities, feed our spiritual needs, and inspire our artistic creations.

Moreover, biodiversity makes us more resistant and resilient. Studies show that people who live in a green environment suffer less from stress or obesity, are more active and take less antidepressants.

While biodiversity disappears, ecosystems become less resilient, and all the services they offer will also fade away.

There is still a lot to learn, how it works!
Marine Metagenomics

- Microbes account for more than 90% of ocean biomass, mediate all biochemical cycles in the oceans and are responsible for 98% of primary production in the sea.
- Metagenomics is a breakthrough sequencing approach to examine the open-space microbial species without the need for isolation and lab cultivation of individual species.
Marine Genome Sequencing Project
Measuring the Genetic Diversity of Ocean Microbes

Sorcerer II data from this area has already reach to 10% of GenBank.

The Entire Data Will Double Number of Proteins in Embank!
Arthrospira is a nutritive food supplement

- Essential Amino Acids
  - isoleucine, lysine, threonine (aspartate family); tryptophan, histidine, phenylalanine, tyrosine (aromatic family)

- Essential Fatty Acids
  - polyunsaturated ω-6 (linoleic acid & GLA) and ω-3 (α-linolenic acid) fatty acids

- Vitamins
  - pro-A, thiamine (B1), B2, B3, panthotenate (B5), pyridoxine (B6), folic acid (B9), cobalamin (B12), ascorbate (C), E, biotin (H), ...

- Pigments
  - β-carotene, phycocyanin, ...

**NUTRIGENOMICS**
Exploit microbial genomics data to assess nutritive value/potential of organism & microbes

**How about**
Marine microbial genomics data management?
Are there European microbial sequence databases?
Are dedicated marine microbial sample or isolate culture collections?
That can be exploited or valorized in biotechnological applications?
Targeted metagenomics as a tool to tap into marine natural product diversity for the discovery and production of drug candidates

Research Engines: Cell Factories

Classic Functional Metagenomic Screening
- Marine sample
- Metagenome DNA extraction
- Generation of a metagenomic library
- Functional screening for desired activity, relying on heterologous expression

Targeted Metagenomic Screening
- Marine sample
- Novel natural product isolation, structure elucidation and biological function determination
- In situ hybridization, single-cell sorting, WGA
- Metagenome DNA extraction
- Sequence based analysis: gene-directed PCR screening / or next generation sequencing of clone library or druggable sequencing
- Metabolite structure elucidation and further functional characterisation

Do you want bio or circular economy? You need ‘synbio’

Synthetic biology is one of the critical ingredients in the bioeconomy.

Synthetic biology sounds like a dream come true: designing new biological organisms with mathematical computer models that will produce new and improved components to a variety of needs in the chemical industry. Perhaps the most exciting aspect of “synbio” lays in its ability to replace most of the oil-based chemicals. This will be one of the key elements in building the bio-based ecosystem, where most of the materials will be produced from renewable or biomaterials instead of oil.
It is not (yet) in our ‘cuisine’ to ‘eat microbes’
ETH researchers have developed a biocompatible ink for 3D printing using living bacteria. This makes it possible to produce biological materials capable of breaking down toxic substances or producing high-purity cellulose for biomedical applications.

There will soon be nothing that cannot be produced with 3D printing. However, the materials used for this process are still “dead matter” such as plastics or metals.

A group of ETH researchers led by Professor André Studart, Head of the Laboratory for Complex Materials, has now introduced a new 3D printing platform that works using living matter. The researchers developed a bacteria-containing ink that makes it possible to print mini biochemical factories with certain properties, depending on which species of bacteria the scientists put in the ink.
Star Trek – food replicator

Captain Jean-Luc Picard from "Star Trek: The Next Generation"
Testing *Arthrospira* as food supplement for space

Development of recipes

Acceptance test during Bedrest studies

Microbiome & health studies on mice, with irradiation

Microbiome studies on human volunteers
(Microbial) Food for space & Radiation protection

Microbial biomass or extracts in feed

SCK•CEN animalarium & expertise in animal biology

Testing Functional properties of (bacterial) nutriceuticals as food supplement and potential radioprotective agent in space

EXTRACTION of a PHYCOCYANIN rich Extract

Lactobacillus probiotic protects intestinal epithelium from radiation injury in a TLR-2/cyclo-oxygenase-2-dependent manner

Inhibitory Effect of Spirulina maxima on the Azoxymethane-induced Aberrant Colon Crypts and Oxidative Damage in Mice
Nutrigenetics & Nutrigenomics – Personalised Food

Harnessing the power of food to change our genes and improve our health

Polymorphic and Mutant Genes
(Changed enzymatic and hormonal activities)

Could the maritime sector find a connection to these new nutritional & health initiatives?

Via our microbiome

Macronutrients (proteins, lipids, etc)
Micronutrient (minerals, vitamins, etc)

The study of how the nutrients in our food interact with our genes
Astronaut of 90 kg = 2.5 kg of microbes
(1-3% of our body weight is bacteria)
~ our brain

Astronaut = 50% Human & 50% microbe
(There are as much microbial cells in our body as human cells)

1 Astronaut = trillions of microbes
= 10 000 ‘s of different microbial species

99 % of the DNA genes are in microbial cells, only 1% in human cells
The Challenge of Maintaining a Healthy Microbiome during Long-Duration Space Missions

Alexander A. Voorhies and Hernan A. Lorenzi

Healthy microbiome during space travel

- Microgravity
- Sleep deprivation
- Stress

Microbiota

- Digestion & Uptake
- Food Components
- Mucus
- Endogenous Substrates
- Food Components
- Non-Digested
- Human Host
- Intestinal Microbiota
- Cellular Binding & Specific Response
- Gastrointestinal Function & Health
- Transformation of Food Components
- Production of Short Chain Fatty Acids

Human microbe:
- Anti-inflammatory activity from fiber intake
- Protection against microbial infections
- Endocrine regulation
- Stimulation of the immune system
- Reduced microbial diversity
- Microbial dysbiosis
- Altered Microbiome

- GCR
- Microrgavity Sleep deprivation Stress

Prebiotics
- Probiotics

Protect

Restore

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Microbes for a healthy space travel & happy

The Human Microbiome
20 Reasons Why Microbes Are Important

- They affect your mental health, thoughts, and behavior
- They help enforce the skin’s protective barrier
- They play an important role in thermoregulation
- They probably affect your skin’s ability to produce vitamin D from sunlight
- They affect the health and functioning of your liver
- They regulate your immune system
- They are capable of neutralizing many toxic compounds
- They impact the insulin sensitivity of various tissues
- They affect the density and strength of your bones

The Bidirectional Gut-Brain Axis

The ability of the brain to influence the intestinal microbiota
- Perfusion of your normal habit via stress-induced changes in gastrointestinal:
  - Physiology
  - Epithelial function
  - Mucin production
  - EE cell function
  - Motility
  - Release of Neurotransmitters

The ability of the microbiota to influence brain, behavior, and mood

Activation of neural pathways to the brain
Activation of mucosal immune responses
Production of metabolites that directly affect the CNS

Nature News Feature
The tantalizing links between gut microbes and the brain
Neuroscientists are probing the idea that intestinal microbiota might influence brain development and behaviour.

Peter Andrews Smith
14 October 2015
If we are capable to keep an astronaut and its environment healthy in space, we should be able to do the same on Earth.
From Space to Earth ....

Our Space Research

- Medical applications
- Health monitoring
- Radiation protection
- Agriculture & food
- Healthy diet
- Waste Treatment
- Resource management
- Water treatment
- Environmental health
- ....
Spirulina as food supplement in DR Congo

- SCK•CEN contribution to the organisation of 'Entrepreneurs for Entrepreneurs'
- project to help fight the malnutrition of Congolese children through the development of local spirulina culture.
- ‘Pilot’ culture & harvest & cooking at SCKCEN run by ‘volunteers’
- construction of an Arthrospira sp. pilot farm in the region of Bikoro in Congo

First test bassin in Mooto

Meeting with local universities for scientific follow-up

Dr. Felice Mastroleo
Thanks to…

‘Molecular and Cellular Biology Group’ (MCB)

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