



Agro-space and quality for a sustainable environment

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Collaborations

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**ASI project
Space Green House**

Mission ENEIDE

Laurea Thesis

Valentina Confidati

Sprouts production in simulated micro-gravity

PhD Thesis

Ing. Carlos M. Rivera Ortiz

Set-up of a soil-less system for growth of leaf vegetables under simulated micro-gravity conditions

Arsial

Lazio Region

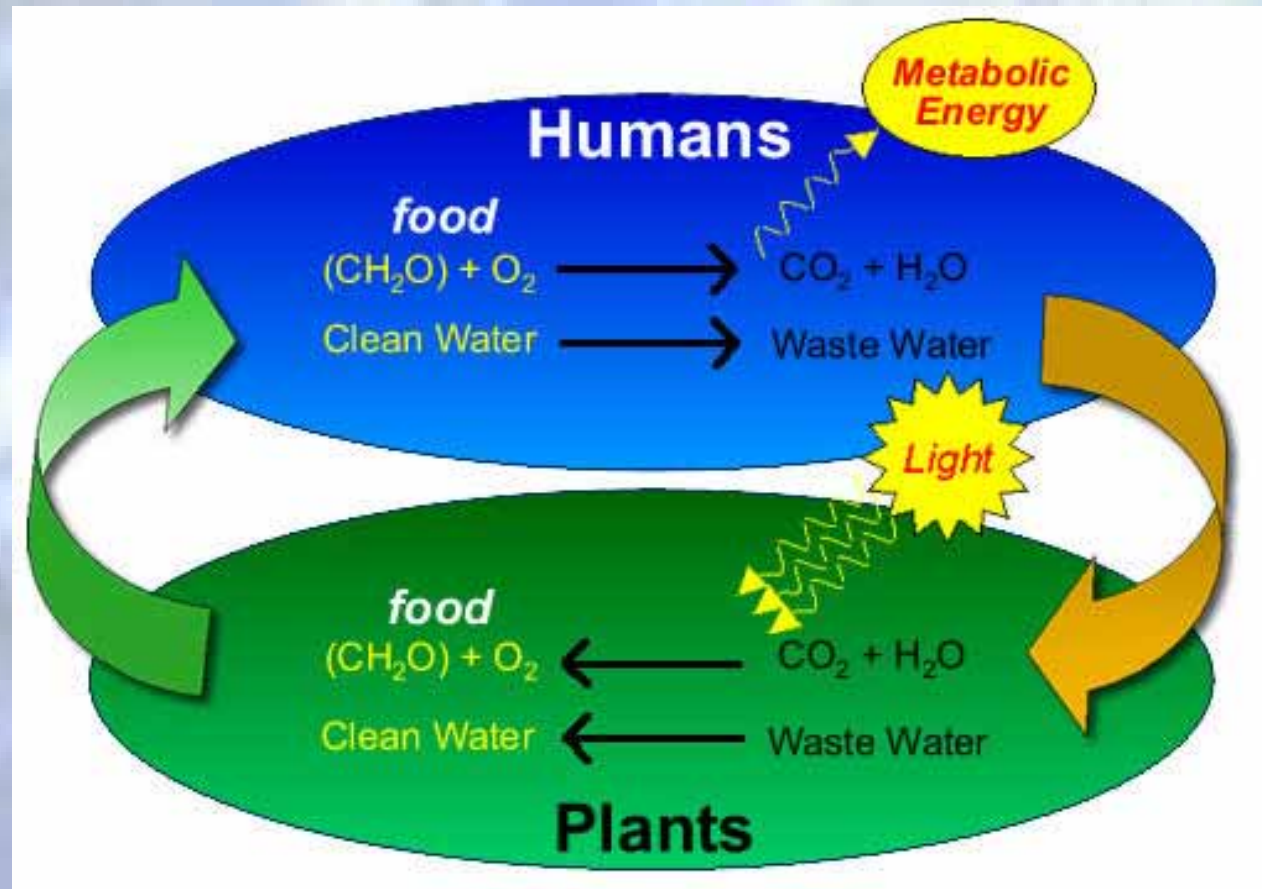
Mission ENEIDE

Soc. Azimuth

Dott. M. Casucci

Mission ENEIDE

Objectives



- Selecting crops and cultivars that are appropriate for different missions: high yield, high harvest index, good nutritional value
- Testing crop responses under controlled environments: light intensity, photoperiod, temperature, and CO₂ concentration
- Developing and testing horticultural systems: water and nutrient delivery, planting and harvesting, materials handling

From: <http://www.jsc.nasa.gov>

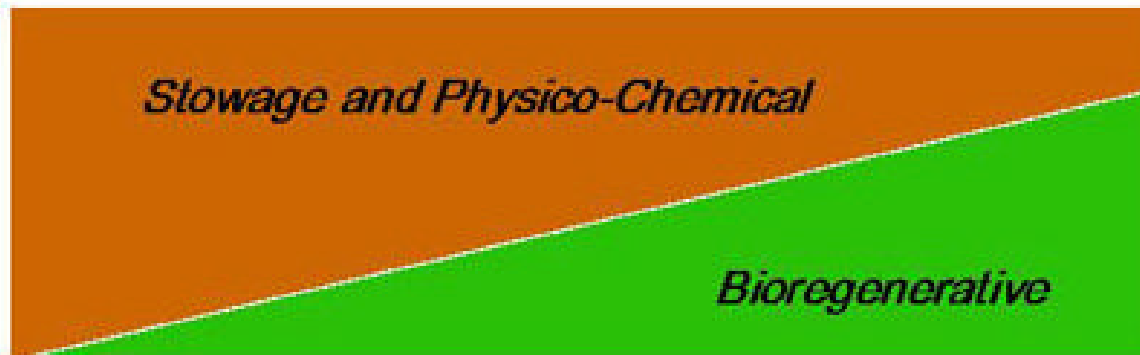
Rationale for the research

Bioregenerative Systems in Future Life Support

*Short Durations
(early missions)*

Longer Durations

*Autonomous
Colonies*



Plant Growing Area

~1-5 m² total

~10-25 m² / person

~50 m² / person

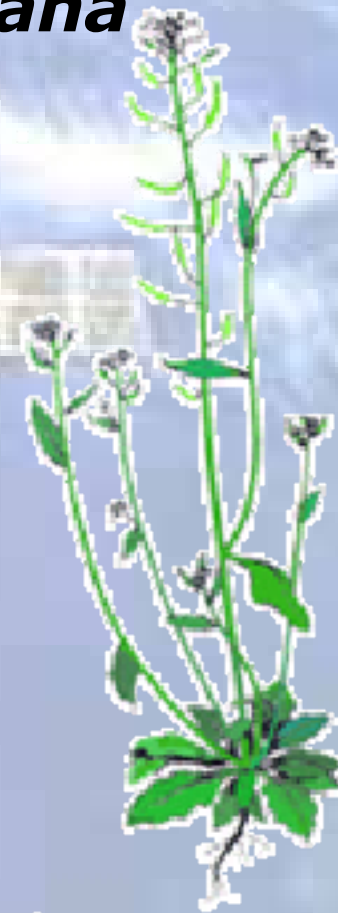
As mission distances and durations increase, so will the cost of re-supply from Earth. Various physico-chemical options are available for regenerating air and water, but as with biological systems, they have associated costs, mass, and power requirements.

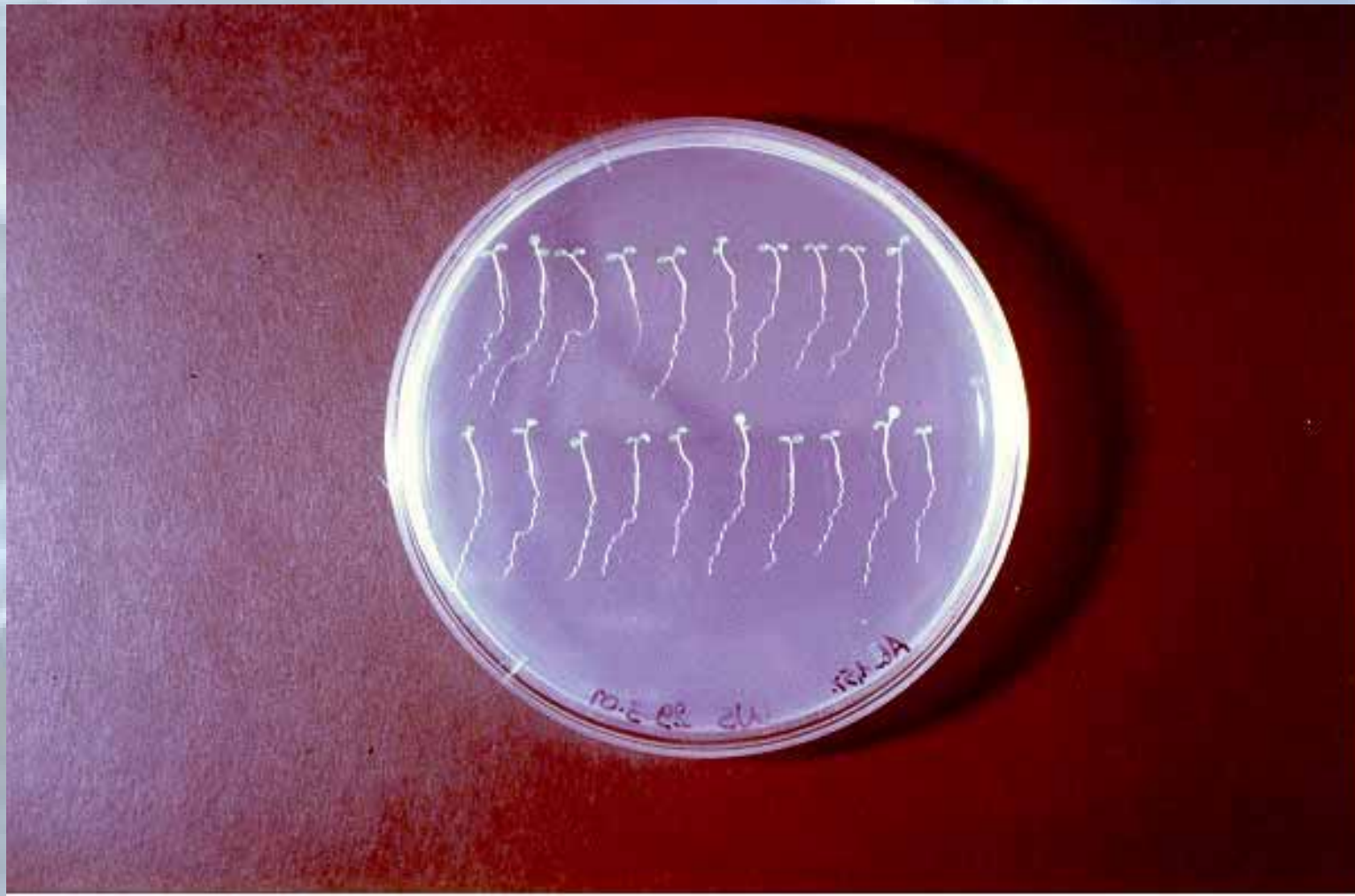
Bioregenerative systems with plants will likely play a larger role as the missions become more autonomous.

Some basic research on growth of plants in the agro-space

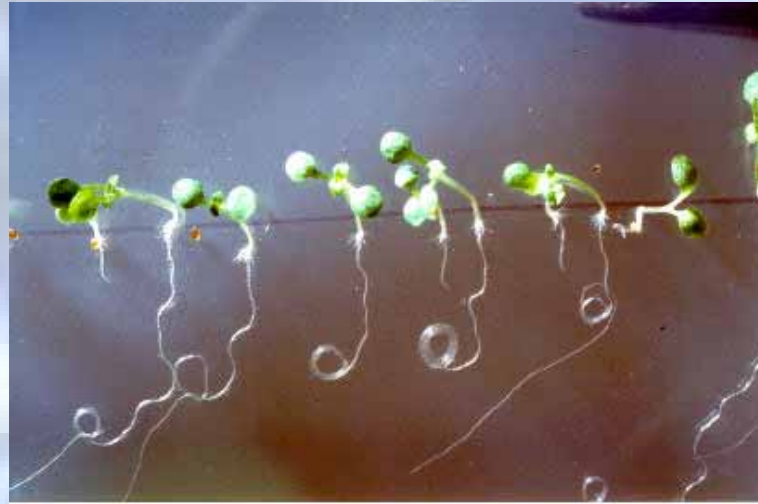
Arabidopsis thaliana

- **Aploid genome
(n = 125 Mb)**
- **Short life cycle
(5-6 weeks)**
- **Autofertile**
- **High seed production**
- **Small size**



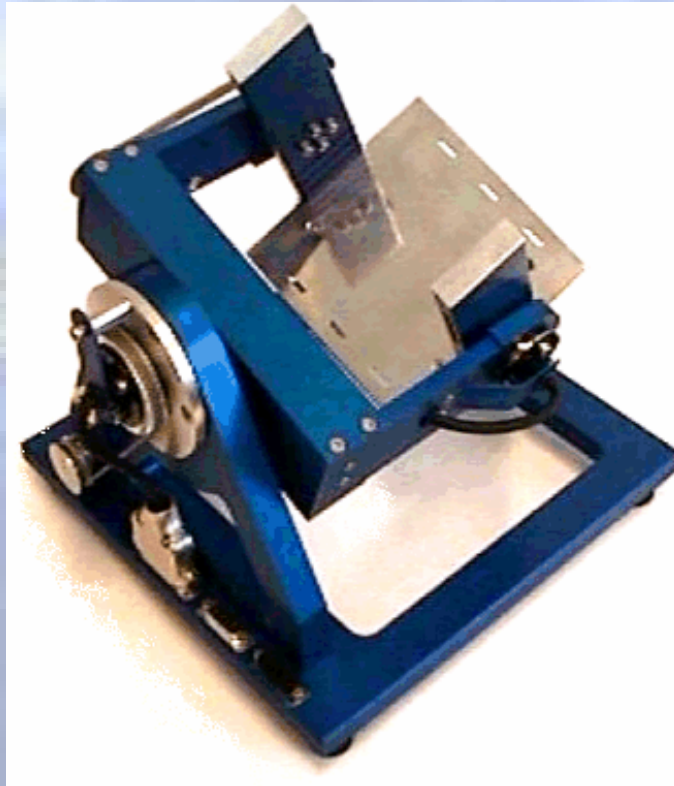


Arabidopsis seedlings growing on a vertical set Petri dish.

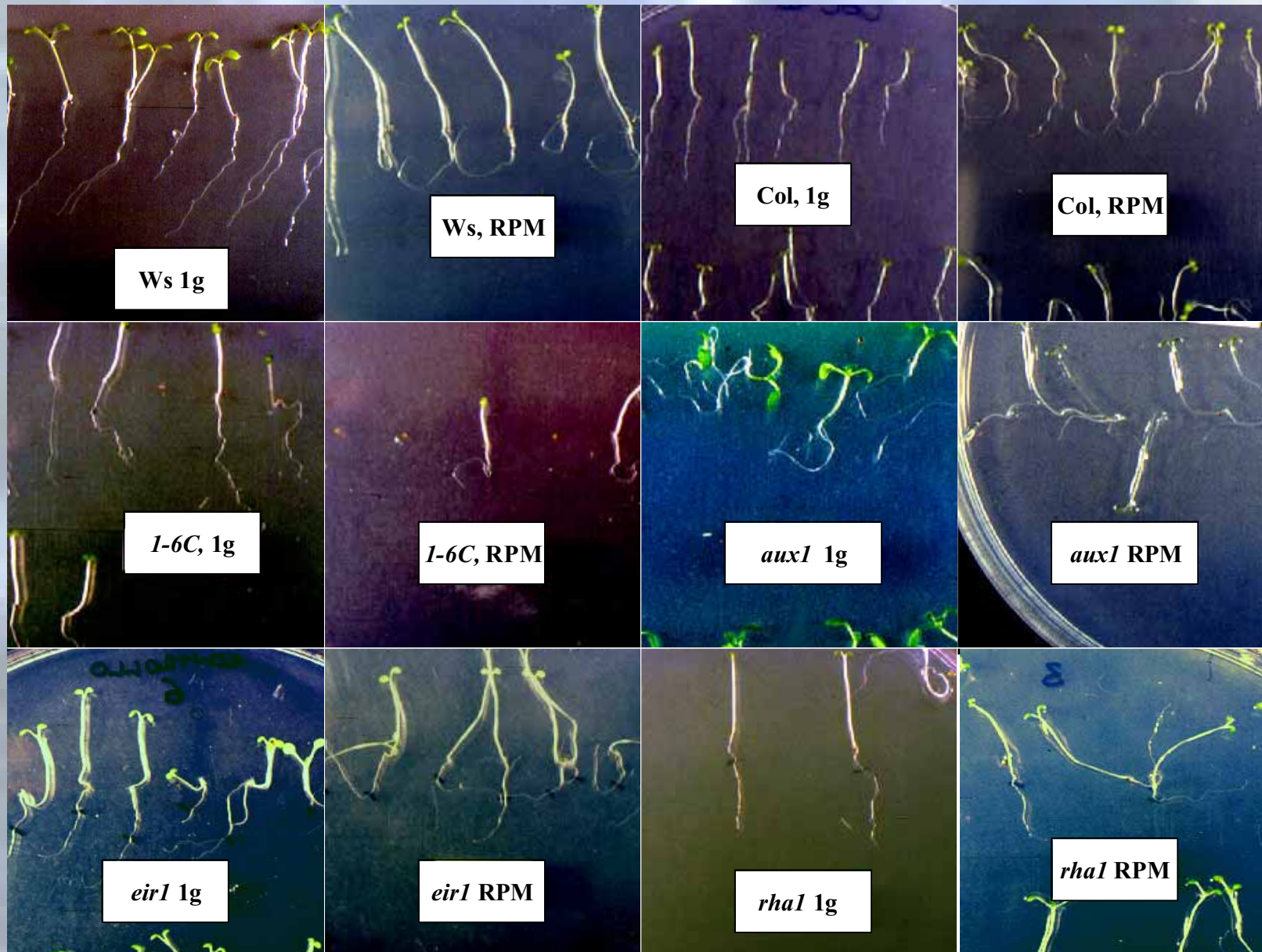


Various forms of growth of *Arabidopsis* roots in wild-type and mutants

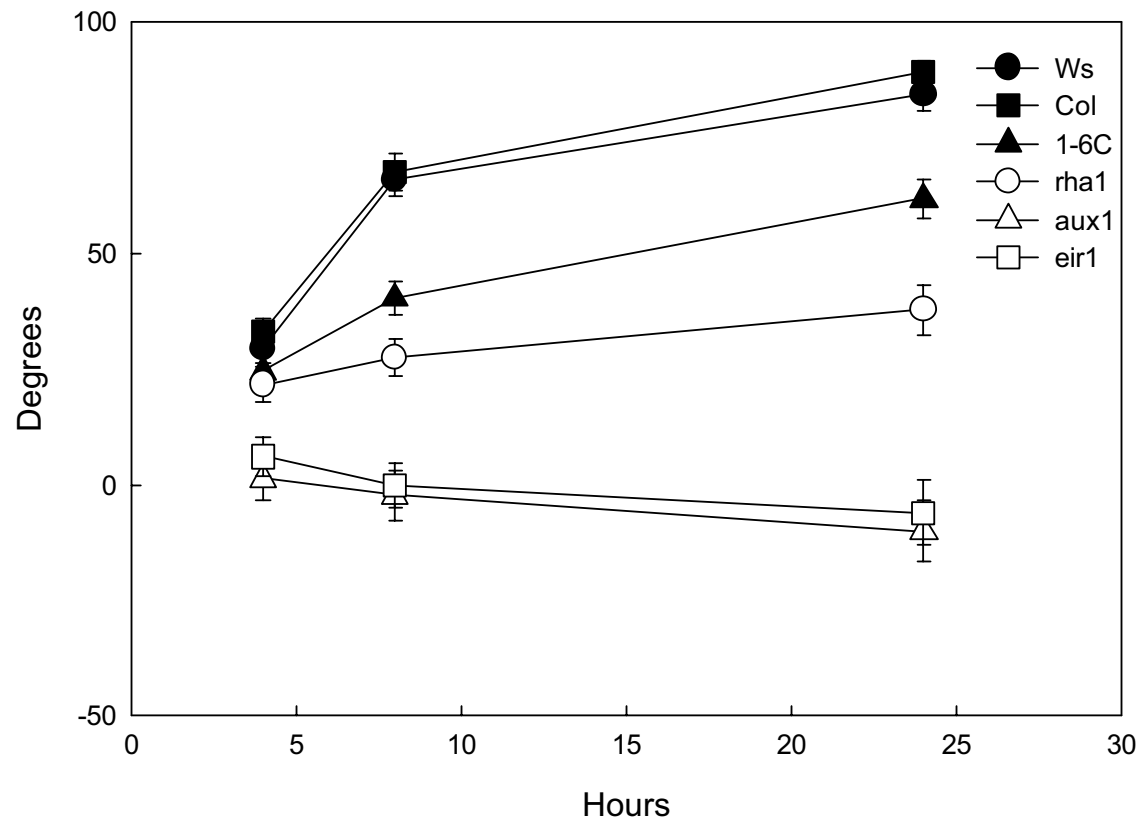
The Random Positioning Machine



The core of the desktop RPM. The footprint of the system is 30×30 cm.



Root elongation of wild types and mutants *Arabidopsis* seedlings under 1g or RPM conditions



Gravitropic response (averages + SE) of primary *Arabidopsis* roots over a 24 hours period

NASA FOOD SYSTEMS

From: Perchonok and Bourland 2002 Nutrition 18: 913-920.

Project Mercury (1961-1963, 34h)

John Glen was the first astronaut to eat in space from an aluminium tube on the third Mercury mission in 1962.

Gemini mission (1965-1966 14gg)

Concentrated food were emphasized. Procedure started for analysis of space food were the beginning of the HCCP

Apollo Program (1968-1972)

Increased variety and quality of food. Astronaut could eat from retort pouches and cans, they had hot water, used irradiated food and open containers with utensils

Skylab program (1973-1974)

72 foods, with a 6-d menu cycle. The mission included freezers, refrigerators, and food warmers. The crew could choose food such as ice cream, filet mignon and lobster, they could also use knife fork and spoon. That program had the best recorded nutritional intake to date for US astronauts.

Space Shuttle (1981-)

Special emphasis was placed on commercial products, more than 350 food were available and astronauts could have a personalised menu.

International Space Station

The focus was on food as Earth-like as possible, there was less emphasis on rehydratable foods. Food is labelled both in English and in Russian

SAMPLE SHUTTLE MENU

Breakfast

Lunch

Dinner

Day 1

Dried apricots (IM)

Oatmeal with brown sugar (R)

Raspberry yogurt (T)

Granola bar (NF)

Orange-grapefruit drink (B)

Chocolate breakfast drink (B)

Mushroom soup (R)

Macaroni and cheese (R)

Tuna salad spread (T)

Tortillas (FF)

Pears (T)

Cashews (NF)

Candy-coated peanuts (NF)

Orange drink with A/S (B), 2

Beef stroganoff with noodles (R)

Rice pilaf (R)

Corn (R)

Vanilla pudding (T)

Dried pears (IM)

Orange-mango drink (B), 2

2, two servings; (B) beverage; (FF) fresh food; (I) irradiated; (IM) intermediate moisture; (NF) natural form; (R) rehydratable; (T) thermostabilized.

SAMPLE CREW MENU ON THE INTERNATIONAL SPACE STATION*

Meal 1

Meal 2

Meal 3

Meal 4

Day 1

Cottage cheese with nuts (R)

bar (NF) Chicken with prunes (T)

Moscow rye bread (IM)

drink (B) Apple-peach juice with pulp (R)

(T)

Tea without sugar (R)

Jellied pike perch (T)

Peasant soup (R)

Almonds (NF)

Pork with lecho sauce (R)

Kuraga (IM)

drink (B) Apple-black current juice with pulp (R)

lemon (B) Tea without sugar (R)

Shrimp cocktail (R)

Beef steak (I)

Macaroni and cheese (R)

Borodinskiy bread (IM)

Strawberry

Tea with

Granola

Peach-apricot

Fruit cocktail

* During the 5-mo stay on the International Space Station, the crew will be on an 8-d rotation system for meals. The menu includes the meals that will be served for each 8-d period. After each period ends, the crew's meals will begin again at day 1. This rotation will continue until the crew leaves the station.

(B) beverage; BBQ, barbecue; (FF) fresh food; (I) irradiated; (IM) intermediate moisture; (NF) natural form; (R) rehydratable; (T) thermostabilized.

FUTURE GOALS

From: Perchonok and Bourland 2002 Nutrition 18: 913-920.

- *The duration of future missions may be as long as 2.5 y and will likely include a stay on a lunar or planetary surface*
- *Food carried from the Earth should have a long shelf life (3-5 y)*
- *Some food will be produced during the mission, it should be healthy and highly acceptable. Systems to produce food should spare space and resources, avoiding the production of large quantities of garbage*
- *Food production should be integrated in Life Support System*

**The first choice is on
Salad crops**

An aerial photograph of a vast agricultural field, likely a rice paddy, showing a complex network of irrigation canals and furrows. The water in the fields reflects the sky, creating a shimmering effect. The overall scene is a top-down view of a large-scale farming operation.

***FOOD QUALITY
depends on:***

Plant species and variety

Production techniques

Environmental factors

Conditions in different “space environments”

Earth



Moon



Mars



ISS



Atm. pressure	101.3 KPa	$3 \cdot 10^{-3}$ KPa	0.7-0.9 KPa	101.3 KPa
Atmospheric composition	77% nitrogen 21 % oxygen water vapor (trace)	25% helium 25 % neon 23 % hydrogen	96% dioxide carbon 3 % nitrogen oxygen, water (trace)	21 % oxygen 0.6 % carbon dioxide
Mean of temperature	15 °C	-23 °C	-63 °C	26.9 °C
Irradiance	1370 W m⁻²	1370 W m⁻²	630 W m⁻²	960 W m⁻²

Growth cabinet SANYO mod. SGM700.1 Including an IRGA PP-SYSTEM WMA-3 for CO₂ control

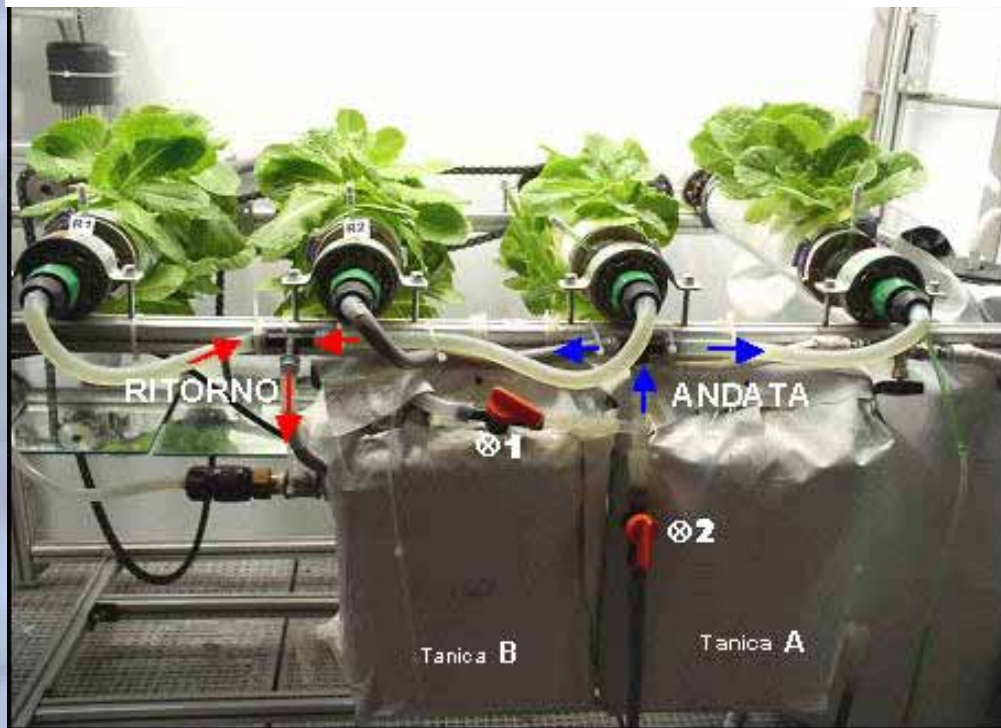
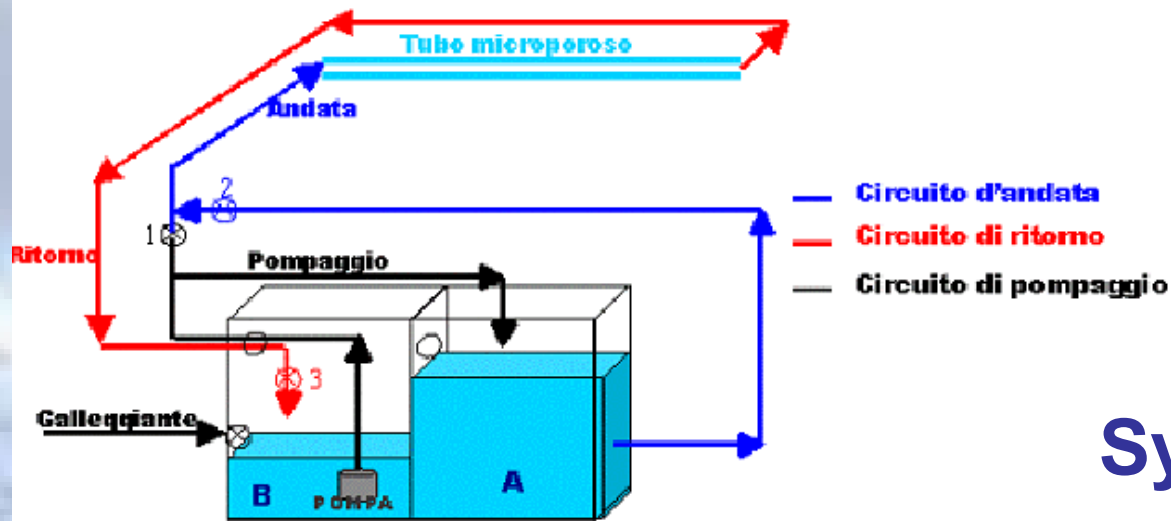
Controlled parameters: Temperature, relative humidity, light intensity and light cycle duration, CO₂ concentration

Temperature: from +7 °C to + 40 °C (in the dark)
from 0 °C to + 40 °C (with light on)

Relative humidity: from 25% to 88% at +40°C
from 42% to 95% at +20°C
from 50% to 95% at +10°C

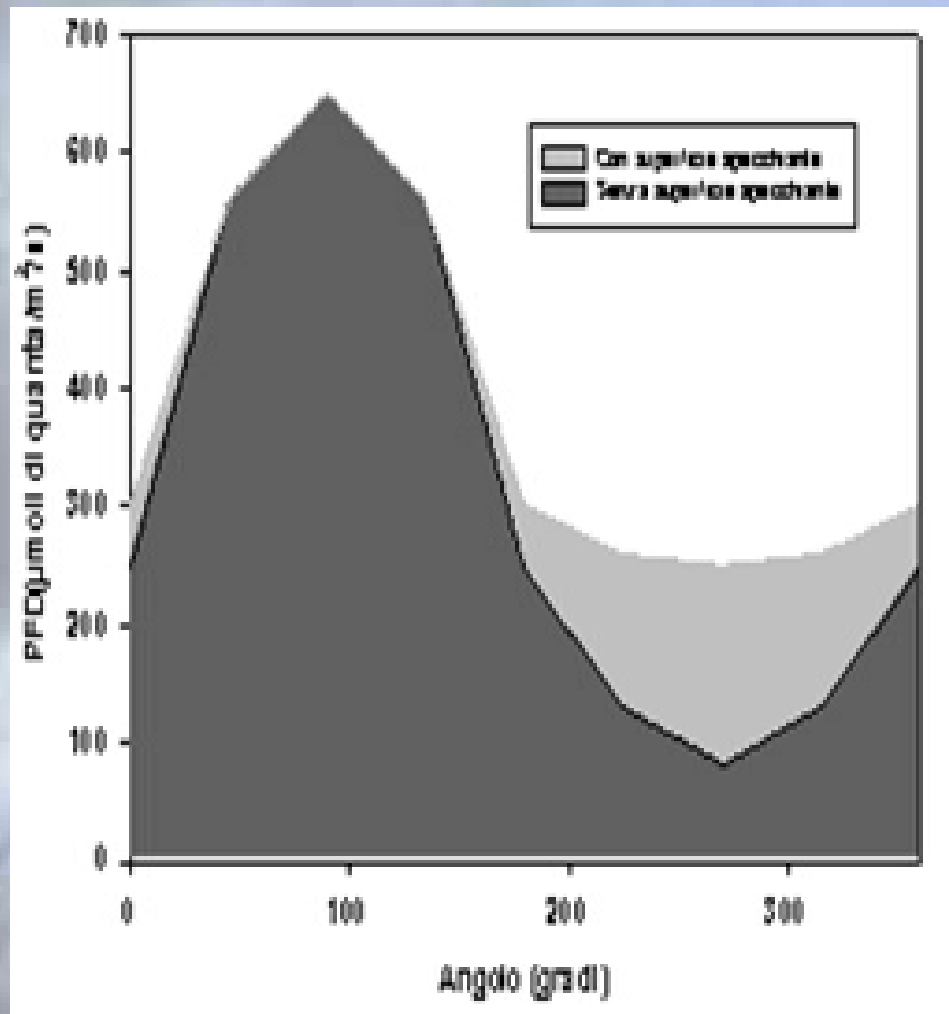
Light intensity: from 0 to 1000 $\mu\text{mol m}^{-2} \text{sec}^{-1}$

CO₂: from 0 to 2000 ppm



System for
soil-less
growth of
plants in
simulated
micro-
gravity
inside the
growth
cabinet

Circuito a sifone. Costruzione
Sopra: schema di funzionamento
Sotto: sistema costruito dentro la camera di crescita



Angolo	Tempo (s)	PFD ($\mu\text{mol di quanta/m}^2/\text{s}^{-1}$)
0	0	300
45	5	560
90	10	650
135	15	560
180	20	300
225	25	260
270	30	250
315	35	260
360	40	300
		Media = 382,22

Intensity of the Photosynthetically Active Radiation at the plant level during a rotation cycle inside the growth cabinet, before (dark) and after (grey) adding reflecting surfaces at the sides of the cabinet



**Simulated
micro-gravity**

Control

Plant appearance

(From Rivera PhD thesis)

**Lettuce leaves
have a normal
appearance that
makes them
perfectly
suitable for salad
preparation**

Characteristics of salad leaves produced under simulated micro-gravity or normal gravity conditions

Tratt	Peso Fresco (PF)	Peso Secco (PS)	Sostanza secca	Area Fogliare	Area Esposta	Peso specifico fogliare su secco	Peso specifico fogliare su fresco
	(g/pia)	(g/pia)	(%)	(cm ² /pianta)	(cm ² /pianta)	(mg / cm ²)	(mg / cm ²)
Clinostato	17,86	1,21	6,85	490,59	327,83	2,45	35,83
Controllo	20,75	2,03	9,74	568,48	371,29	3,55	36,46
	NS	**	***	NS	NS	***	NS

NS, *, **, *** Non significativo o significativo a $P \leq 0,05$, $0,01$ e $0,001$ rispettivamente

(*) Rapporto parte epigea/ipogea

Characteristics of salad leaves produced under simulated micro-gravity or normal gravity conditions

Tratt	Clorofille Totali (mg / g PS)	Carboidrati totali (g /100g PF)	Proteine (g / 100g PF)	Vitamina C (mg /100g PF)	Nitrati PPM
Clinostato	12,46	0,71	0,69	16.2	618
Controllo	18,54	2,42	0,58	27.0	557
	***	***	*	*	NS

Characteristics of salad leaves of different varieties produced under simulated micro-gravity or normal gravity conditions

	Glucosio (g /100g PF)	Fruttosio (g /100g PF)	Saccarosio (g /100g PF)	Amido (g /100g PF)	Solubili (g /100g PF)	Carboidrati Tot (g /100g PF)	Proteine Totali (g /100g PF)
Varietà (V)							
2171	0,616 ^a	0,720 ^a	0,363 ^{ab}	0,116 ^a	1,699 ^a	1,815 ^{ab}	0,488 ^b
2186	0,723 ^a	0,854 ^a	0,498 ^a	0,149 ^a	2,076 ^a	2,225 ^a	0,666 ^a
2197	0,396 ^b	0,472 ^b	0,313 ^c	0,179 ^a	1,181 ^b	1,361 ^c	0,596 ^a
Trattamento (T)							
Clinostato	0,384 ^b	0,491 ^b	0,285 ^b	0,104 ^b	1,159 ^b	1,263 ^b	0,543 ^b
Testimone	0,773 ^a	0,874 ^a	0,498 ^a	0,193 ^a	2,144 ^a	2,337 ^a	0,624 ^a
Significanza							
V	**	***	NS	NS	**	*	**
T	***	***	**	*	***	***	*
V*T	NS	NS	NS	NS	NS	NS	NS

Bags for vegetable production in space



Eruca sativa plantlets grown during the mission ENEIDE

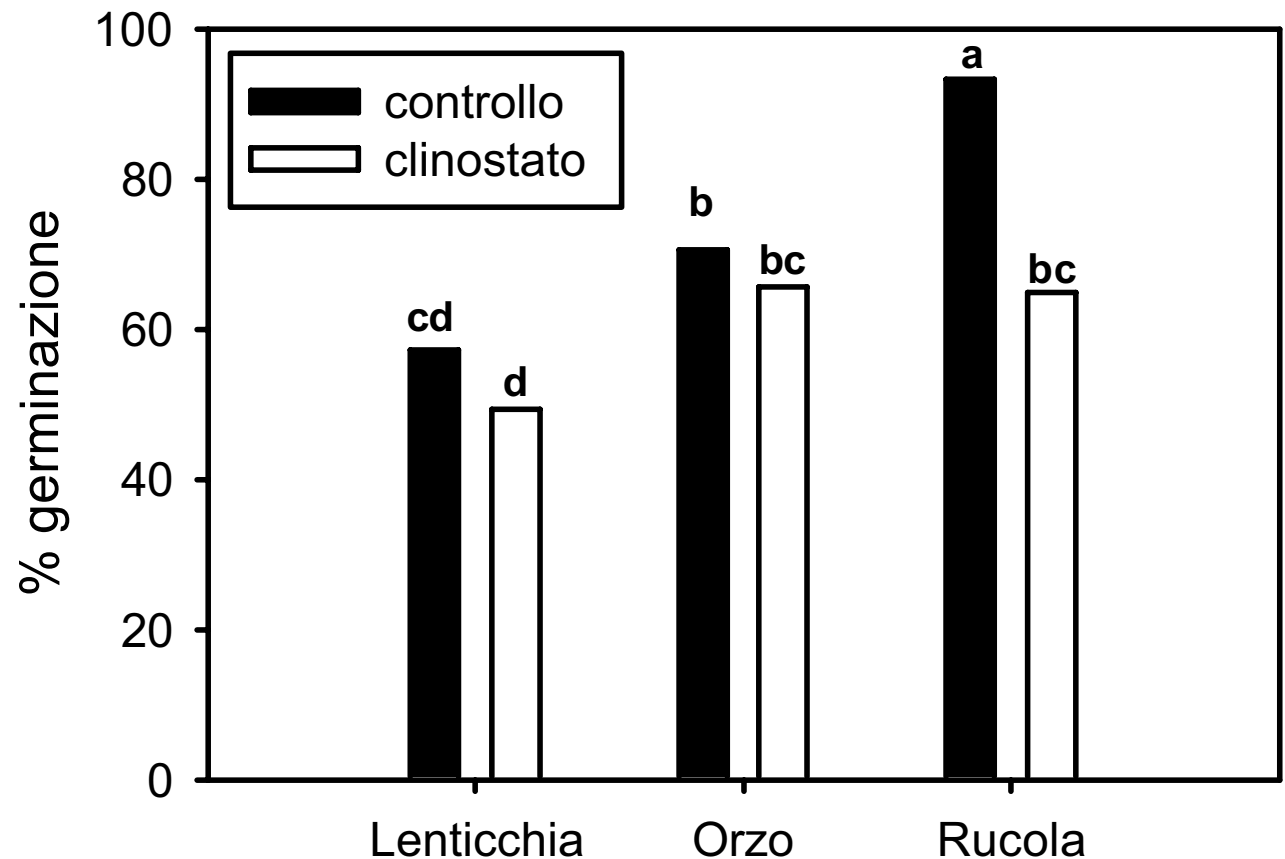


Effect of simulated micro-gravity on germination of seeds of different species

(From: Confidati thesis of Laurea)

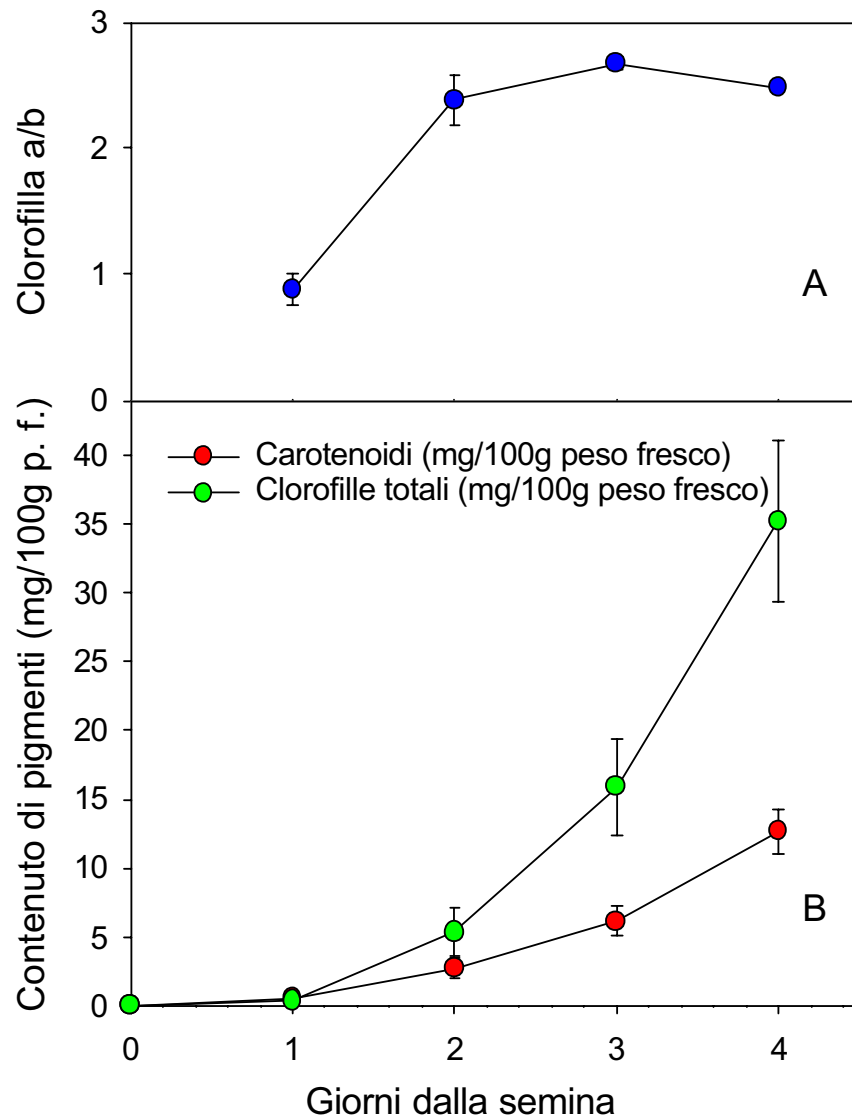
Simulated micro-gravity effects differ in different species.

Although the *Eruca sativa* seed are the most affected they still maintain a high % of germination



Effects of the factors SPECIES e and SIMULATED MICRO-GRAVITY, on the contents of chlorophyll, carotenoids and C vitamin.

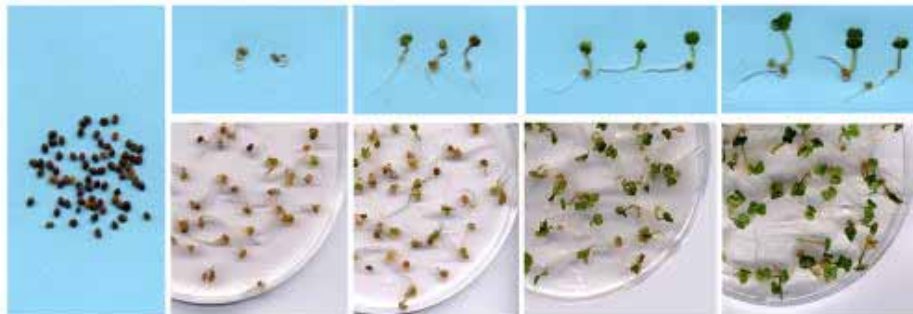
	Clorofilla mg/100g p.f.	Carotenoidi totali mg/100g p.f.	Vitamina C mg/100g p.f.
Specie			
Rucola	24,5 a	7,7 a	57,8 a
Lenticchia	5,4 c	1,5 c	36,0 b
Orzo	13,1 b	3,0 b	17,9 c
Clinorotazione			
Assente	14,4 a	4,1 a	37,0 a
Presente	14,2 a	3,9 a	37,6 a

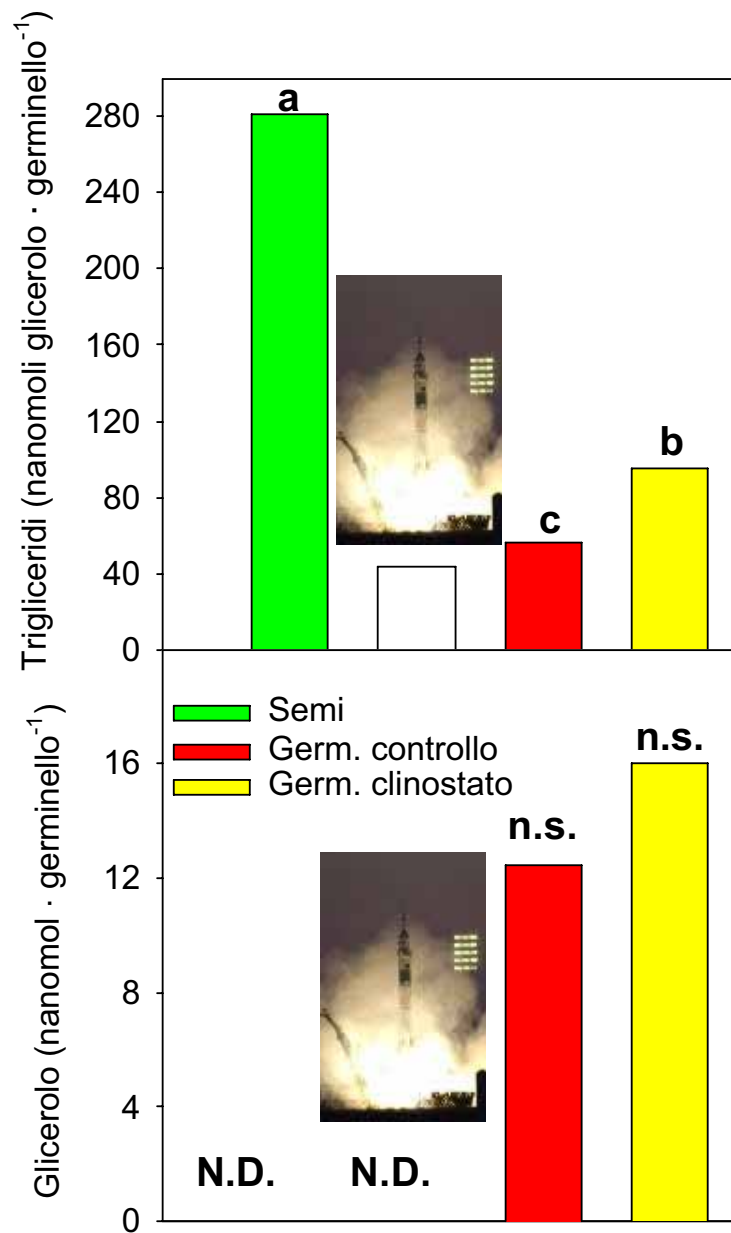


Plantlets soon became photosynthetically competent, this is linked to:

the increase of the chlorophyll content (important for the appearance)

The increase of the carotenoids linked to the structure of the photosynthetic apparatus, (important as antioxidants and pro-vitamins for the nutraceutical value of the sprouts salad)





Triglycerides content fall during germination while free glycerol content increases.

The simulated micro-gravity decreases the speed at which triglycerides are used by the growing plants indicating a slowing down of germination and growth .

Plantlet from the ENEIDE mission had low triglyceride indicating that germination was completed .

Synopsis

- **It is possible to produce fresh food in the agro-space**
- **Environmental conditions, though not optimal, allow the growth of green plants**
- **Food quality is acceptable, with good nutraceutical values**
- **Large differences among plant species and genotypes in responses to the agro-space environment; large improvements in the plant growing systems**

Research foresight: How to improve the space environment

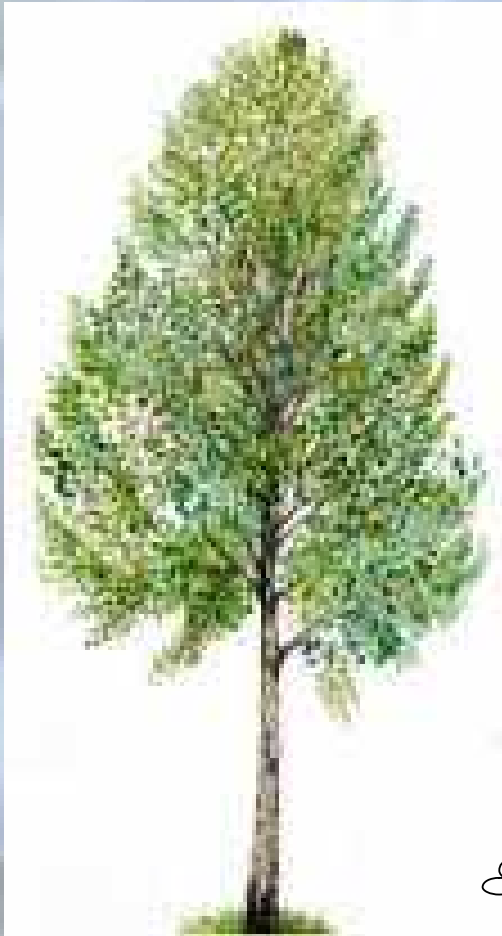


Artist's conception of a space habitat called in Mars the [Stanford torus](#), by [Don Davis](#)



An artist's rendering of a lunar base. (NASA)

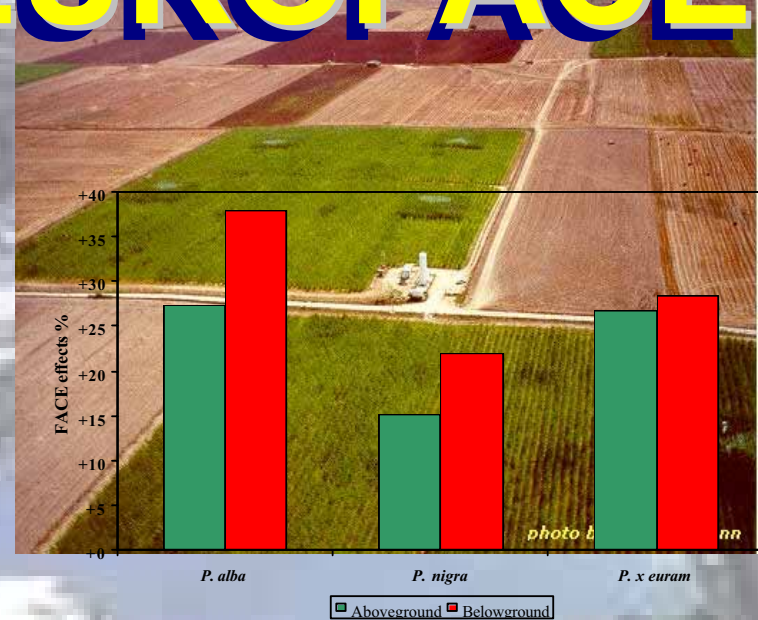
Which plants to grow
and how to grow
them, for improving
the space
environment?



EUROFACE



Experiments conducted on trees growing under elevated CO₂ may provide interesting results for the space environment





Grazie

