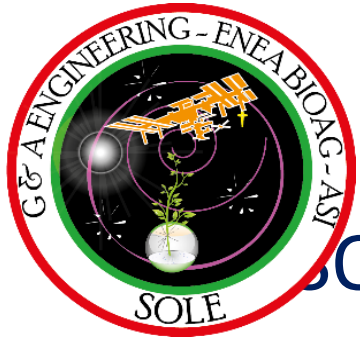




2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING
A CIRCULAR
FUTURE



SOLE project: a hydroponic greenhouse demonstrator for fresh food production in space

E. Bennici¹, E. Benvenuto¹, M. Crisconio², A. Desiderio¹, E. Di Mascio³, Francesca Ferranti², M. Garegnani^{1,4}, L. Giuliani¹, L. Nardi¹, C. Pacelli², G. Pontetti², M. E. Villani¹



EITHUB
●●● ELETTRONICA GROUP



COMPANY HISTORY



1996

G & A ENGINEERING
Foundation
2 DEPT



G & A
Engineering®

PRIVATE RESEARCH CENTER
For Microelectronic for Space Application

INNOVATIVE SME
Defence and Aerospace

PMI INNOVATIVA
registroimprese.it

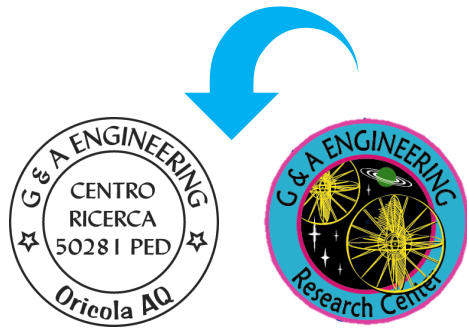
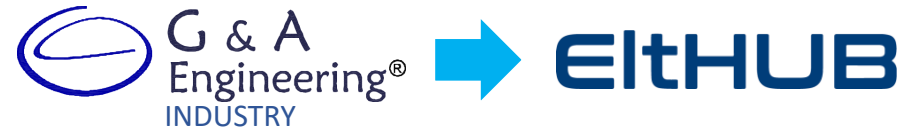




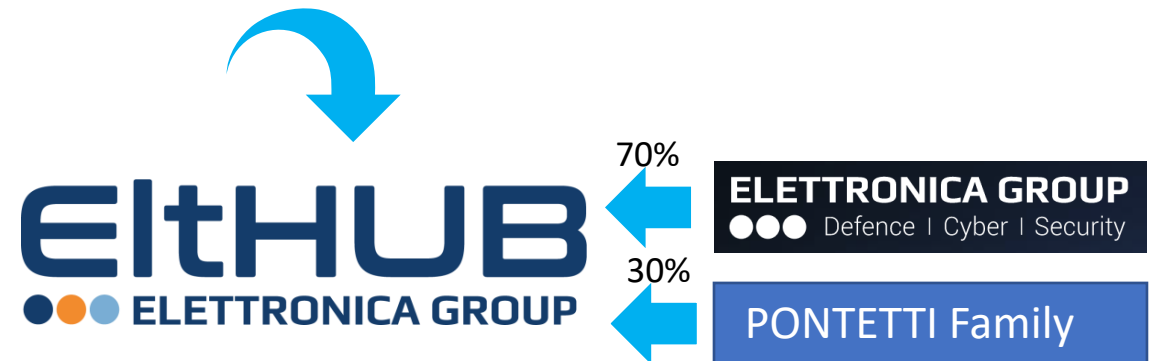
COMPANY HISTORY



May 2022



PRIVATE RESEARCH CENTER
For Microelectronic for
Space Application



INDUSTRY
Defence, Aerospace,
Hydroponic,
Automotive, Medical



THE COMPANY



18.000

SQM

5

WORKSHOPS

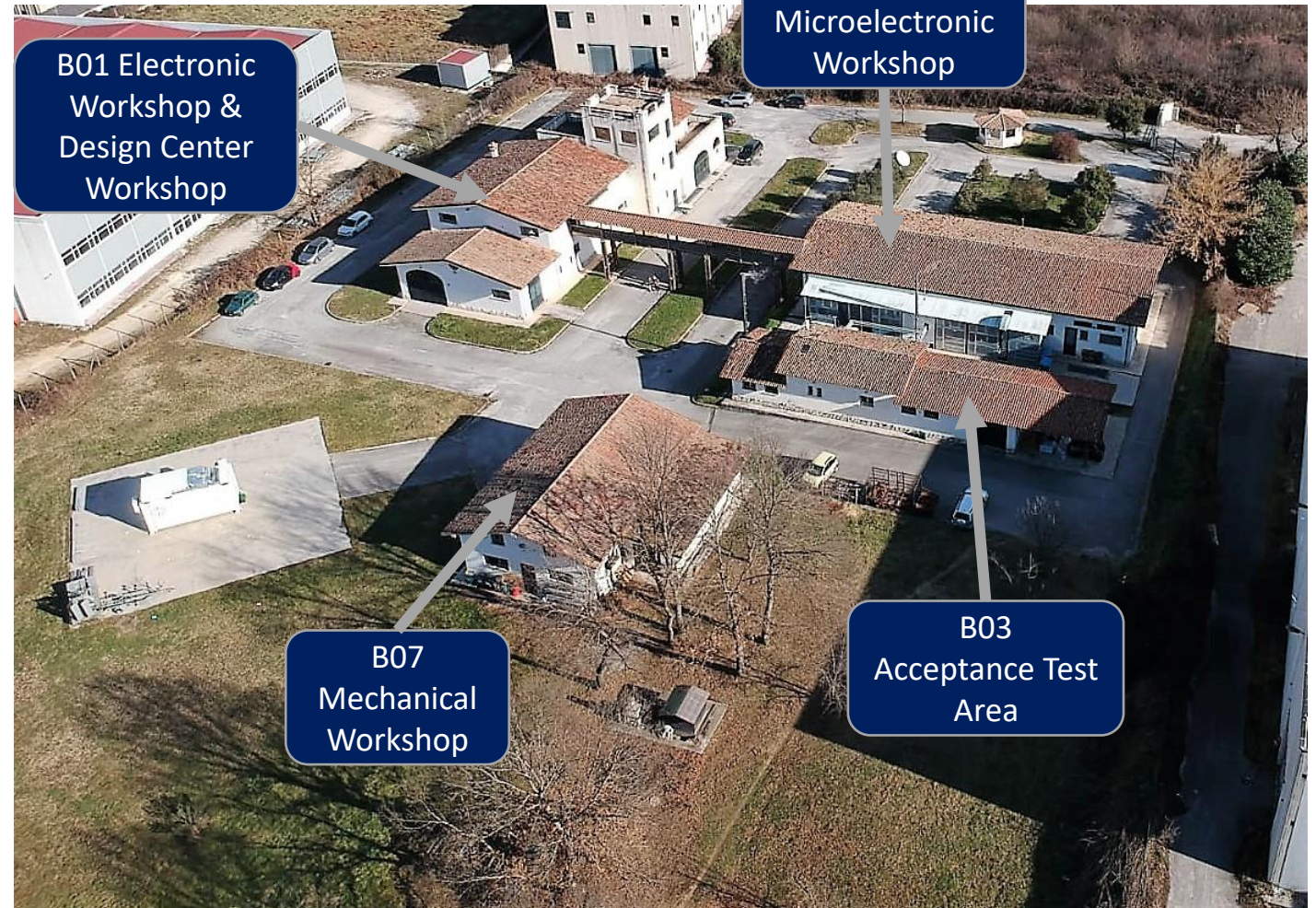
SA 8000

BUREAU VERITAS
Certification



ISO 9001
ISO 14001

BUREAU VERITAS
Certification





THE COMPANY



A personnel focused company having a mix of skills, high tech internal technologies and industrial processes

14



2.5

M€

TURNOVER

70%



5 LOB



2

Research Projects
PON Agrifood
& PNRM



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Leonardo S.p.A.
Airbus Italia S.p.A.
Malvern Panalytical BV
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Private Companies





CEA



An entire LOB dedicated to create a line of hydroponic products.

- ✓ **RobotLamp**, the best performing LED lamps on the market
- ✓ **RobotFarm**, the hydroponic greenhouse in the size of a washing machine
- ✓ **Hydrowall**, the hydroponic vertical farm in the size of a planter
- ✓ **MIG**, the vertical farm in container ISO20 for extreme applications
- ✓ **SOLE**, the hydroponic vertical farm designed to cultivate in Space

A **Patent** for Electronic Cultivation Recipe for CEA systems

FARMING HAS NEVER BEEN **EASIER**

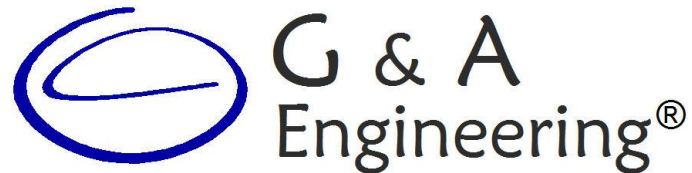


THE « SOLE » PROJECT



A plant greenhouse demonstrator for the soilless cultivation of plants, based on solid state artificial lighting (LED).

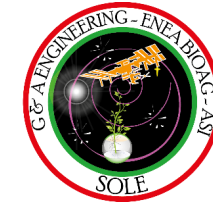
The project studied the best light recipes for duration, intensity and spectral quality, optimized to achieve the different phases of plant growth.



The goal is to use this demonstrator to support research for future manned space missions, to carefully evaluate the resources needed to produce adequate quantities of fresh food, reducing the astronaut's operating times.



BACKGROUND



Future human long-term space exploration demands for fresh food production during missions, independently on periodic supplies from Earth.

The possibility to grow plants in space positively impacts both astronaut diet and psychological wellbeing.

It has been estimated that a facility of a few cubic meters is sufficient to supply the diet of 4 to 6 crew members with key vitamins and fresh bioactive substances.

Soilless cultivation is the best suited for production of high quality food in space, where resources are limiting factors.

In this context, the project SOLE aimed to realize a hydroponic cultivation module based on LED lighting systems for growing plants, specifically microgreens, for space applications.



SOLE DEMONSTRATOR

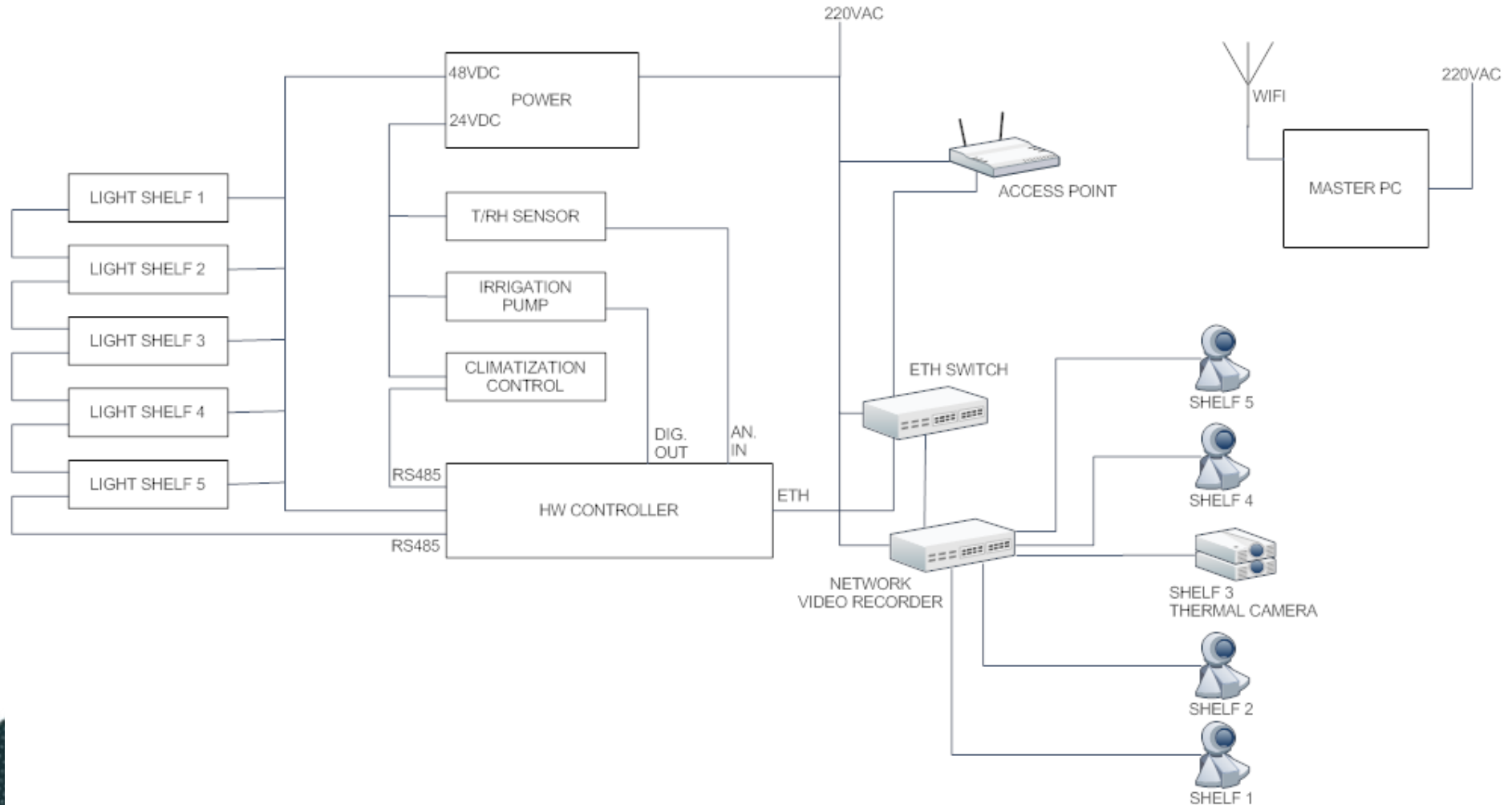


SOLE is a hydroponic vertical farm built in a closed environment, fully controlled and the light radiation for photosynthesis (PAR) is provided by Proprietary LED lamps.

The cultures are arranged on 5 trays that can be lighted independently, while climate and irrigation parameters are in common.

The command and control system is Proprietary and is divided into MASTER and HW CONTROLLER units. The MASTER consists of a PC external to the device, while the HW CONTROLLER consists of a Proprietary board with microprocessor. The two units communicate with a MODBUS protocol over Ethernet through the Wi-Fi network of SOLE. The MASTER has the task of providing the HMI interface, managing the automatic execution of cultivation recipes processes, allowing maintenance operations and storing system operating data, the HW CONTROLLER has the responsibility of managing the hardware by applying the commands from the MASTER.

BLOCK DIAGRAM





DEMONSTRATOR DESIGN



The SOLE demonstrator has been designed for the automatic hydroponic cultivation of microgreens, baby leaf and dwarf species.

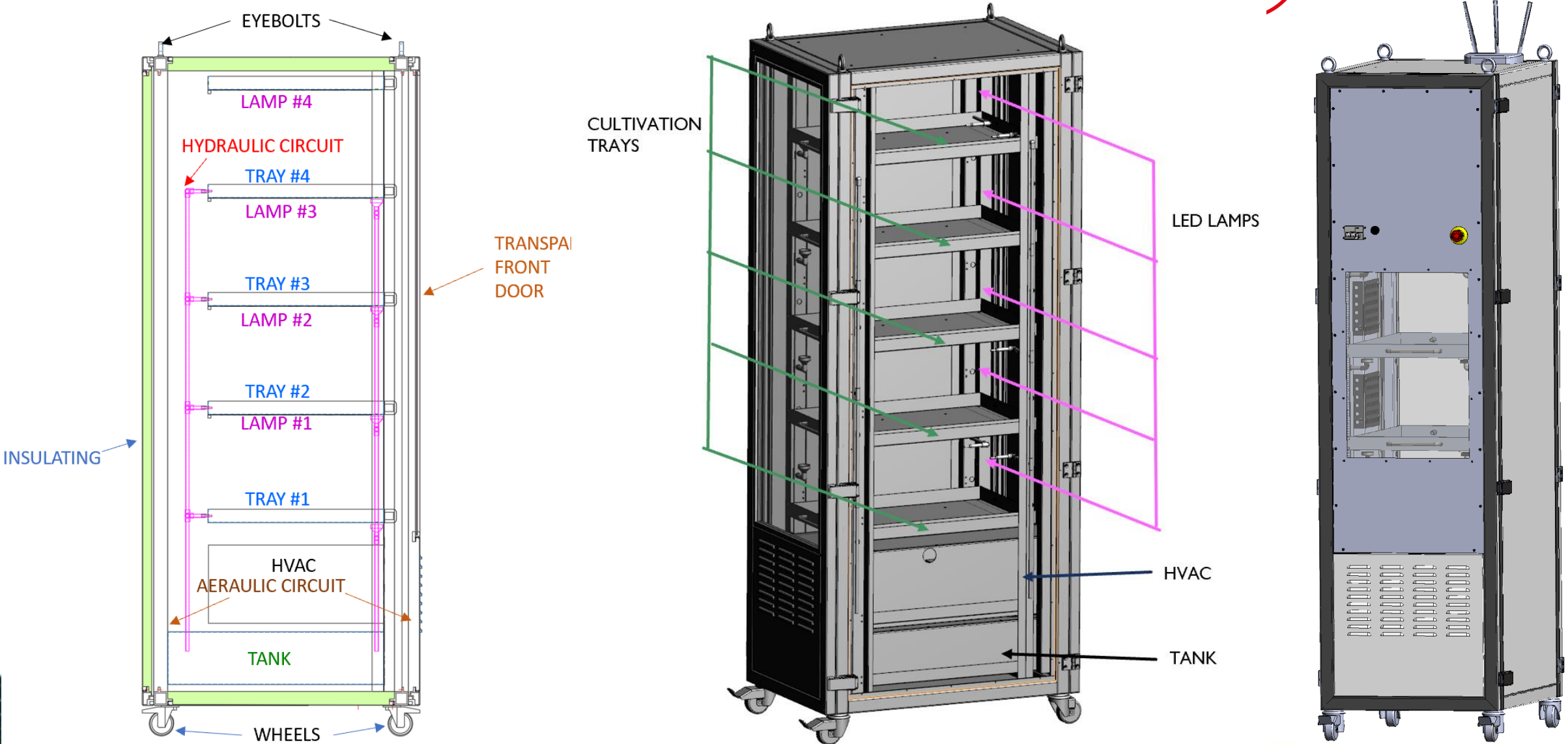
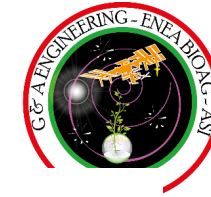
It consists of a modular cabinet implemented with cultivation trays, light, HVAC, aerodynamic and hydraulic systems.

The cabinet was realized in aluminium alloy, which ensures excellent mechanical properties and low weight. It was insulated to minimize energy dispersal and external environmental influence and was equipped with temperature, pressure and relative humidity sensors, as well as a real-time video monitoring system.

The demonstrator can be operated and controlled remotely using a LAN connection and a simple user-friendly HMI.



SOLE DEMONSTRATOR



MELISSA

SOLE DEMONSTRATOR

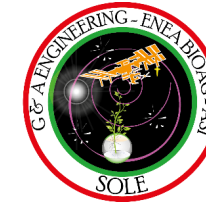


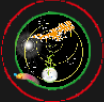

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SOLE HMI



RECIPESSCHEDULINGHISTORY

SHELF 5 CULTIVATION DAY: 12/20
DESCRIPTION: 06:00 - 22:00 @50%

SHELF 4 CULTIVATION DAY: 12/20
DESCRIPTION: 06:00 - 22:00 @50%

SHELF 3 CULTIVATION DAY: 12/20
DESCRIPTION: CIME DI RAPA

SHELF 2 CULTIVATION DAY: 12/20
DESCRIPTION: 06:00 - 22:00 @50%

SHELF 1 CULTIVATION DAY: 12/20
DESCRIPTION: every 4h@1min

PAUSE CLIMATE CONTROL






PAUSE LIGHTING CONTROL

PAUSE IRRIGATION CONTROL

TEMPERATURE SET POINT: 21.0°C
TEMPERATURE MEASURE: 0.0°C
HUMIDITY MEASURE: 0%

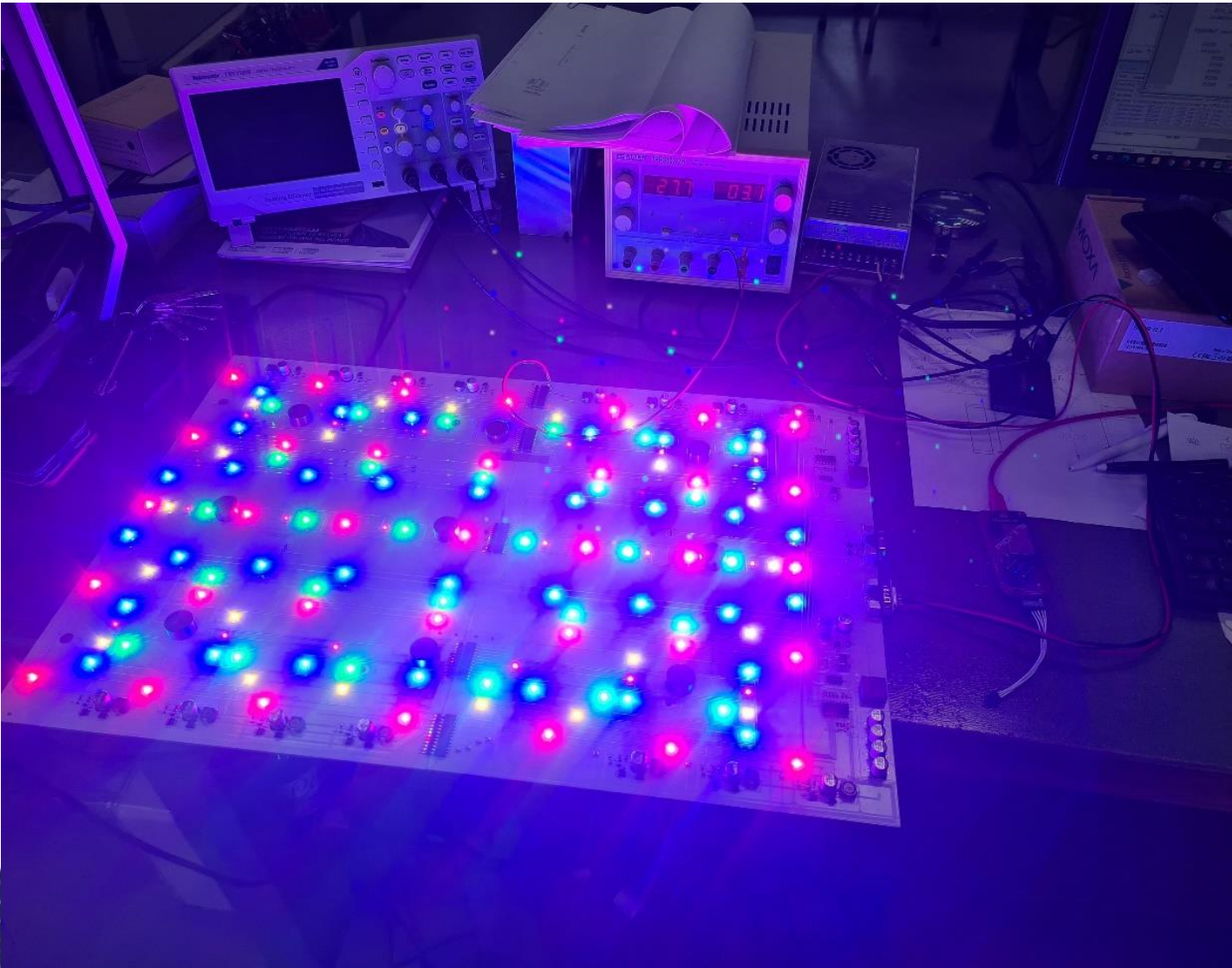
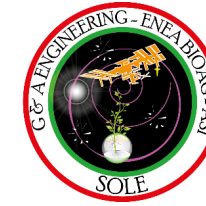
HVAC HEATER

LEVEL: REGULAR

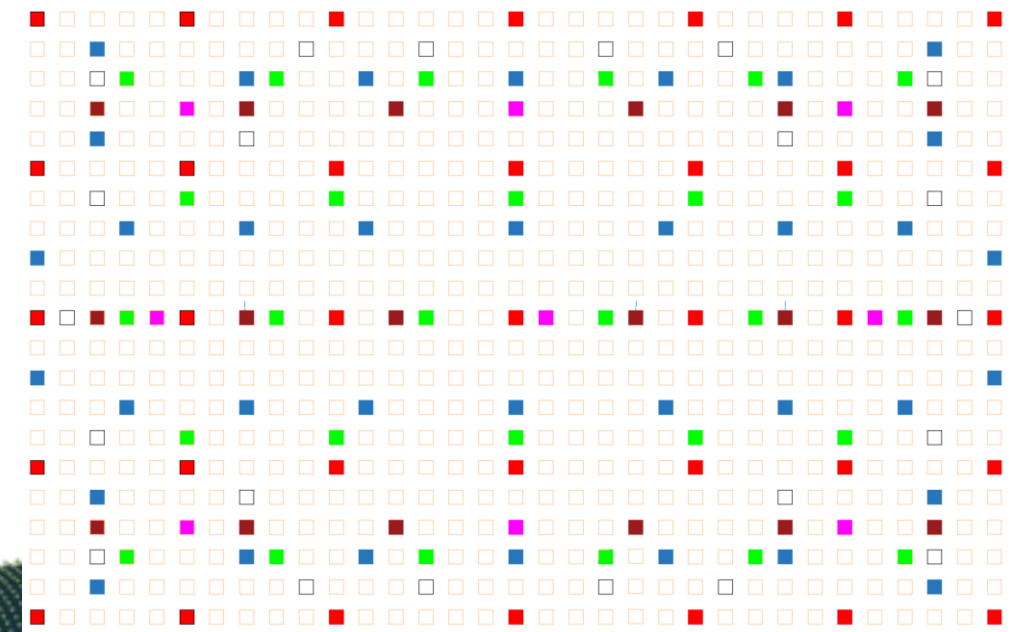
22/02/2022 10:11:26EXIT



SOLE LED LIGHTS

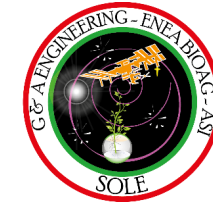


COLOR	WAVELENGTH	DOMINANT
Deep Blue	439 – 461 nm	451 nm
Far Red	720 – 740 nm	730 nm
Hyper Red	635 – 666 nm	660 nm
True Green	513 – 545 nm	521 nm
UV-A	380 – 440 nm	395 nm
White	3000K	N/A





CULTIVATION CONDITIONS



Temperature:

+21°C to +25°C, adjustable

Relative Humidity:

40% to 60%, adjustable

Irrigation Cultivation Recipe:

1.30 min every 4 hours, adjustable

Recipe Cultivation Lights:

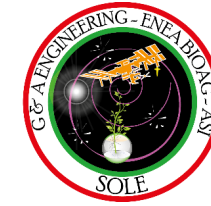
18 h Light, 6 h Dark

150 $\mu\text{moles}/\text{m}^2\cdot\text{s}$

Red 40% - Green 20% - Blu 40%



CULTIVATION CONDITIONS



Nutritive Solution:

Cultivation Surface:

Seed Germination:

Custom Prepared

pH 7

68 x 43 cm = 2.924 cm²

48h @ dark, +25°C, 90% RH

In this phase the imbibition of the seed takes place.

The seed swells and metabolic processes are activated.



CLEAN, SANITIZATION & SOWING



Before starting the cultivation it is necessary to carry out a cleaning and sanitizing cycle in order to guarantee the absence of pathogens for cultivation.

The procedure used is summarized below:

- Sterilize the seed in a 2% v/v hydrogen peroxide aqueous solution for 10 minutes
- Rinse in demi-water three times
- Dry the seeds in clean sterile paper
- Clean all cultivation trays with a 2% v/v hydrogen peroxide aqueous solution
- Cut out the Greenfelt mats to match the grow trays dimension
- Sterilize the Greenfelt by spraying hydrogen peroxide 2% v/v for 15 min before sowing
- Sterilize the tank with a 2% v/v hydrogen peroxide aqueous solution
- Prepare the nutrient solution to fill the tank
- Place the Greenfelt mats on the cultivation trays and carry out a watering cycle with the nutrient solution
- Sow





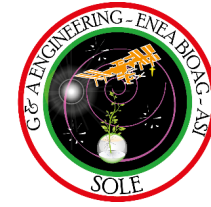
CULTIVATIONS TEST



TURNIP TOPS



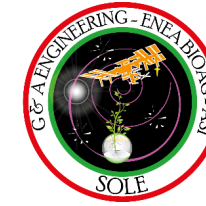
CULTIVATIONS TEST



TRAY DIVISION	
LETTUCE	BROCCOLI
CABBAGE	RADISH



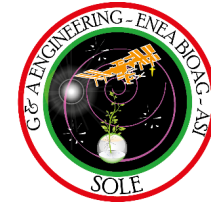
CULTIVATIONS TEST



TRAY DIVISION	
MUSTARD	BEANS
LENTILS	ROCKET



CULTIVATIONS TEST



● ○ REDMI NOTE 9
∞ AI QUAD CAMERA

TRAY DIVISION	
CUCUMBER	CHARD
ROCKET	VALERIAN



CULTIVATIONS TEST



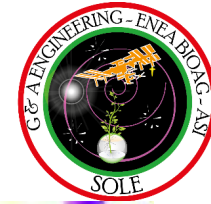
TRAY DIVISION	
CHICKPEAS	ENDIVE
CHICORY	RED CABBAGE



TRAY DIVISION	
KOHLRABI	CLOVER
TURNIP TOP	BRUSSELS SPROUT



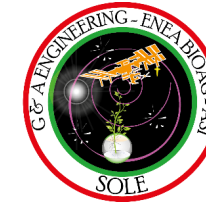
CULTIVATIONS TEST



TRAY DIVISION	
RED CABBAGE	RADISH
BROCCOLI	ROCKET



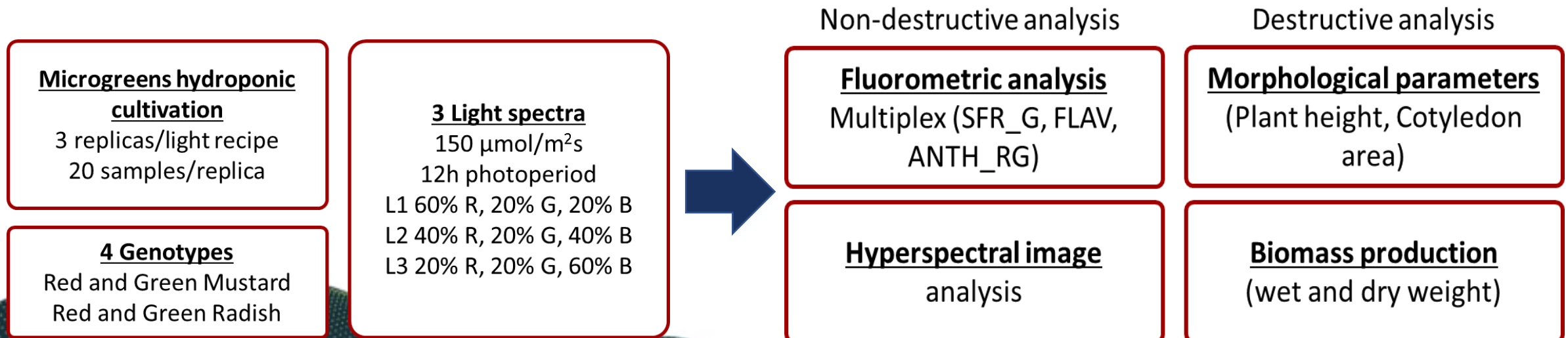
EXPERIMENTAL TRIALS



SOLE cultivation experiments were conducted in **ENEA's** facilities.

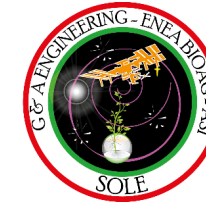


Morphometric (hypocotyl height, cotyledons area, fresh and dry weight), **fluorometric** (Multiplex index analysis SFR_R, FLAV, ANTH) and **hyperspectral analysis** (Specim IQ camera + Evince sw) were conducted on red and green microgreen species: Radish (*Raphanus sativus*) and Mustard (*Brassica juncea*).





EXPERIMENTAL TRIALS



Plants were cultivated with three different light recipes to evaluate the best spectra in terms of primary and secondary metabolism development.

3 Light spectra

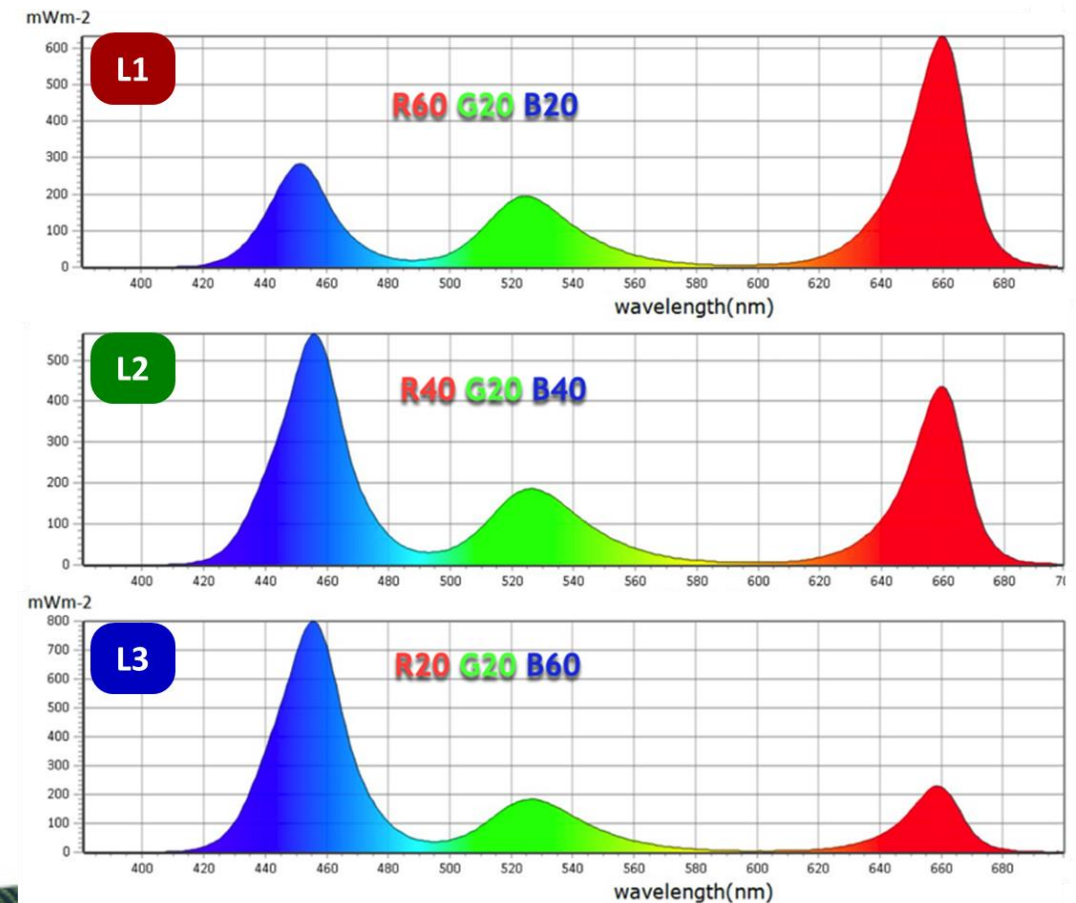
150 $\mu\text{mol}/\text{m}^2\text{s}$

12h photoperiod

L1 60% R, 20% G, 20% B

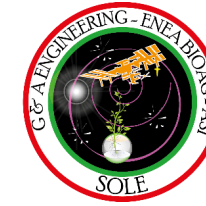
L2 40% R, 20% G, 40% B

L3 20% R, 20% G, 60% B





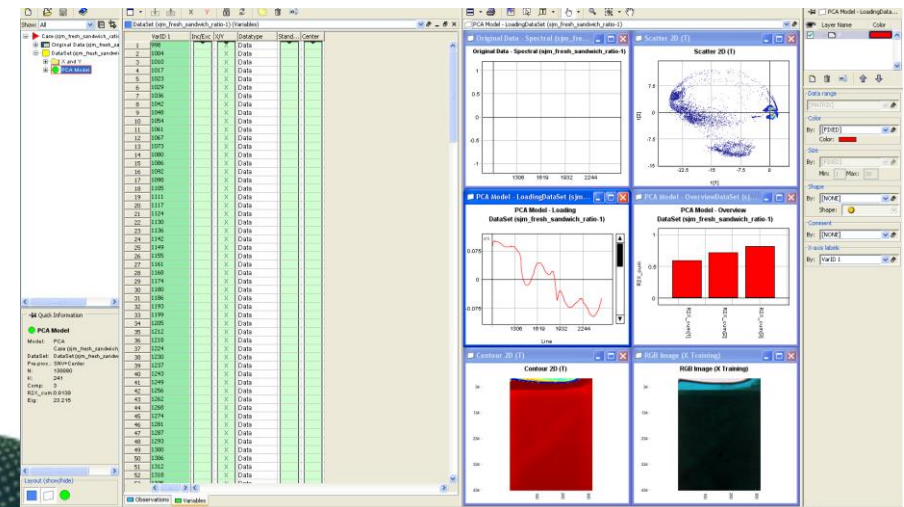
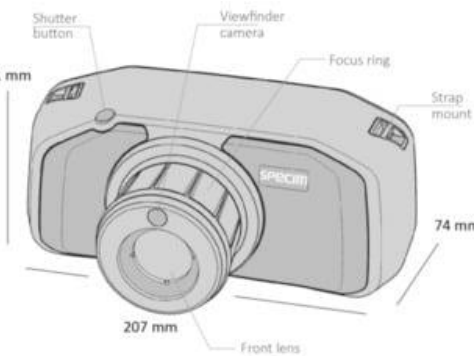
HYPERSPPECTRAL ANALYSIS



The images were acquired by means of a **Specim IQ** hyperspectral camera, with an acquisition interval between 400-1000 nm.



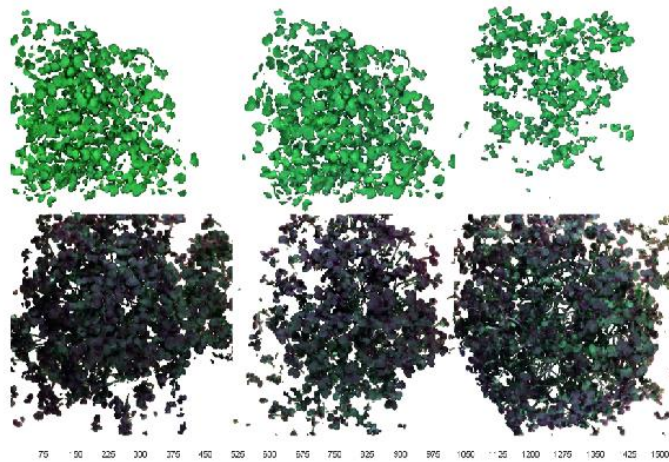
The **Evince software** was used for the analysis of the images, the extraction and processing of the data present in the images, which allows to process, analyze and obtain results thanks to the integrated advanced statistical analysis package specific for hyperspectral images



(A)

RGB Image (X Training)

75
141
208
275
341
408
475
541
608
675
741
808
875



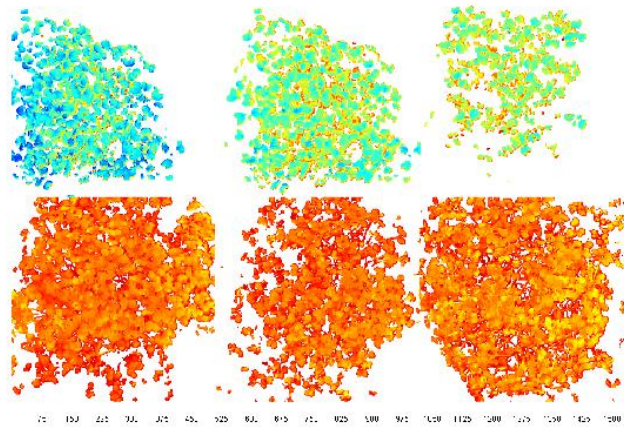
Senape Green Frills

Senape Red Carpet

(B)

PCA Model - Contour 2D (T)
DataSet (Multi image import)

75
141
208
275
341
408
475
541
608
675
741
808
875
941
1008
1075



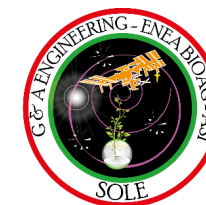
Senape Green Frills

Senape Red Carpet

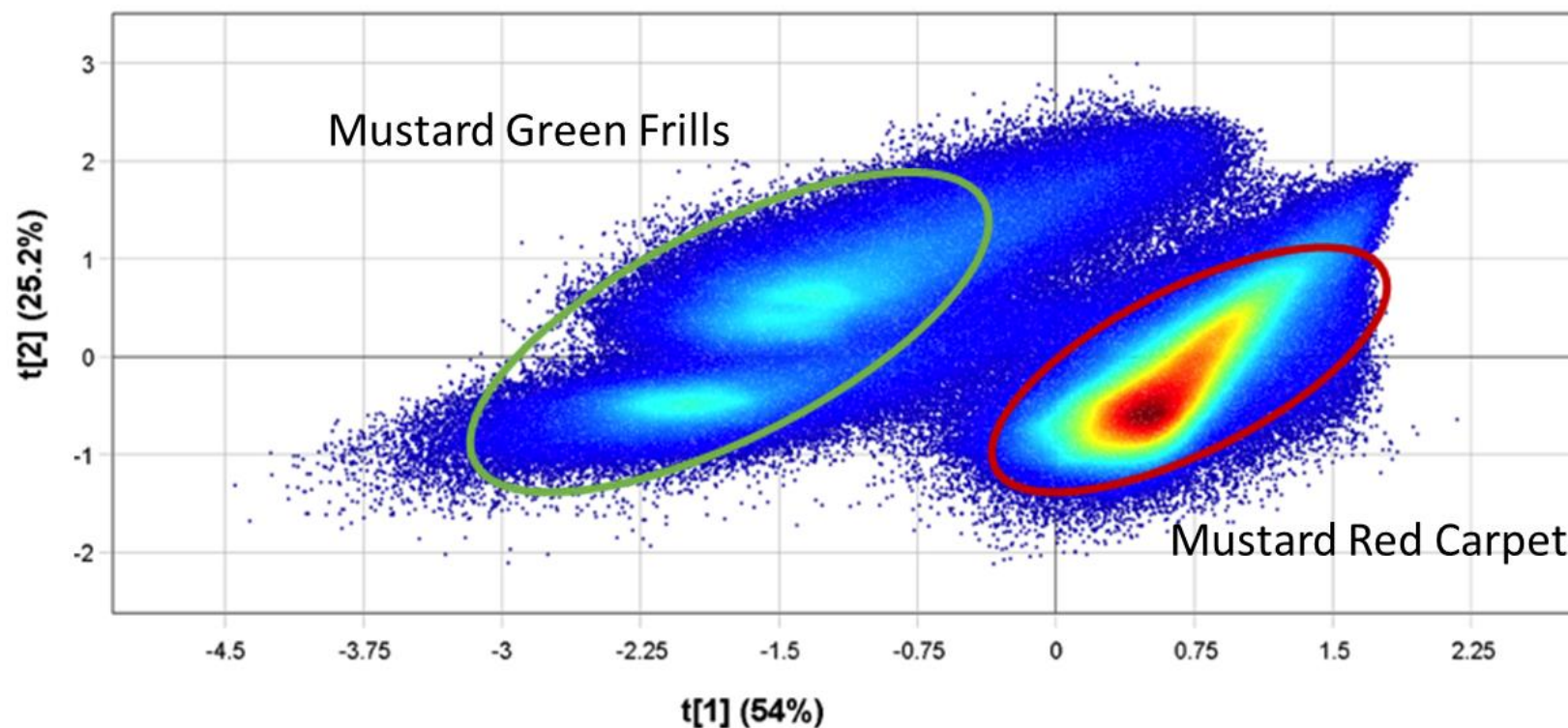
RGB image of the Green Frills and Red Carpet mustard samples used for display in RAW format (A) on which the PCA (Principal Component Analysis) analysis was conducted and of the responses due to the analyzed variables (B).



HYPERSPECTRAL RESULTS



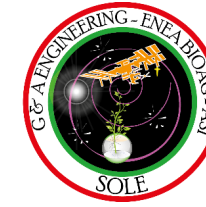
PCA Model - Scatter 2D (T)
DataSet (Multi image import)



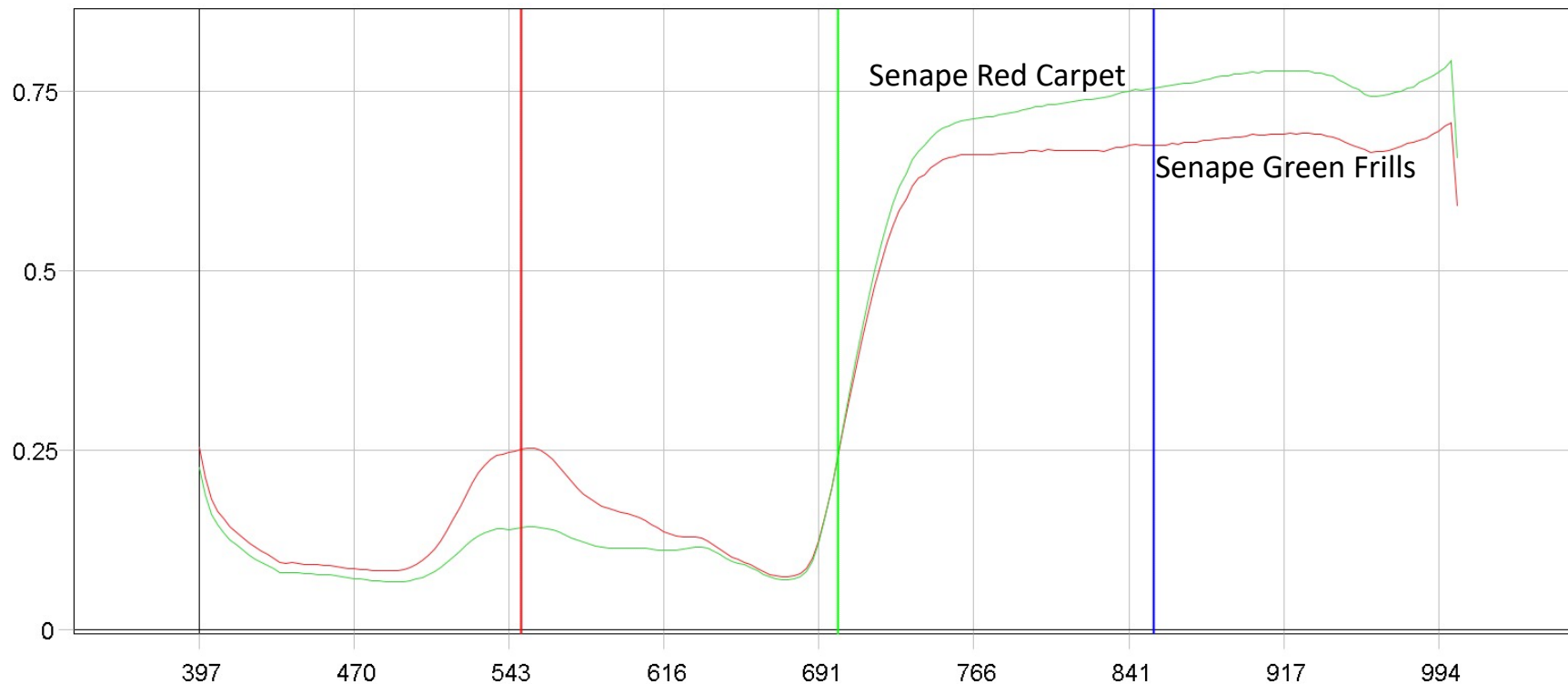
2D Scatter plot from a PCA (Principal Component Analysis) of a hyperspectral image of two mustard cultivations (Green Frills vs. Red Carpet). Colour density highlights the difference between the two cultivations.



HYPERSPECTRAL RESULTS



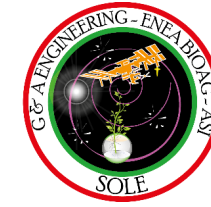
Spectral (X Training)
DataSet (Multi image import)



Lines Plot for the analysis of average spectral data, which allow to identify spectral bands discriminating between Mustard "Green Frills" and "Red Carpet"



FLUOROMETRIC ANALYSIS



Fluorometric analysis with Multiplex (ForceA portable fluorometer):

- **SFR_R** index related to leaves chlorophyll concentration
- **FLAV** index related to leaves flavonols concentration
- **ANTH_RG** index related to leaves anthocyanins concentration

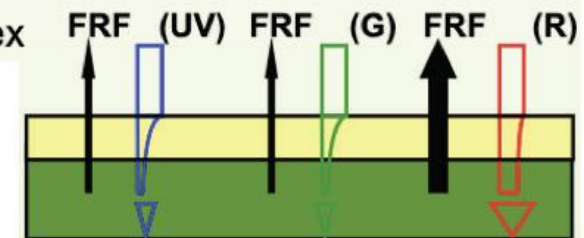


CALCOLI DEL MULTIPLEX

- FLAV content $FLAV = \log \frac{FRF_R}{FRF_UV}$
- Anthocyanins content $ANTH = \log \frac{FRF_R}{FRF_G}$
 $ANTH = \log \frac{5000}{FRF_R}$
- Chlorophyll content $SFR = \frac{FRF_R}{RF_R}$

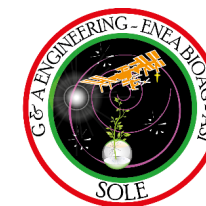
- NBI: Nitrogen Balance Index

$$NBI_G = \frac{FRF_UV}{RF_G}$$





FLUOROMETRIC RESULTS



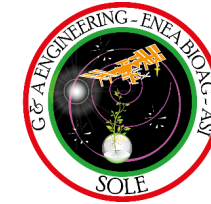
Mustard	Green Frills				Red Carpet			
	ANOVA	L1	L2	L3	ANOVA	L1	L2	L3
Wet weight (g)	ns	0,0865	0,0800	0,0931	***	0,0390	0,0579	0,0222
Dry weight (g)	ns	0,0045	0,0049	0,0034	*	0,0028	0,0029	0,0013
Hypocotyl height (mm)	*	63,4	74,3	66,1	***	28,9	43,6	18,5
Cotyledons area (mm ²)	**	125,0	169,7	104,9	***	112,3	151,5	73,3
SFR_G	ns	0,8577	0,8432	0,7425	**	0,7555	0,8305	0,7278
FLAV	ns	-0,0001	0,0240	0,0249	ns	-0,0005	-0,0211	-0,0259
ANTH_RG	ns	-0,0395	-0,0279	-0,0334	*	0,0527	0,0240	-0,0203

Radish	Green Daikon				Rioja Improved			
	ANOVA	L1	L2	L3	ANOVA	L1	L2	L3
Wet weight (g)	*	0,3226	0,3529	0,2621	****	0,1870	0,2118	0,1461
Dry weight (g)	*	0,0150	0,0174	0,0141	*	0,0092	0,0110	0,0079
Hypocotyl height (mm)	ns	74,4	68,3	57,6	*	61,6	54,2	48,4
Cotyledons area (mm ²)	**	471,9	584,0	419,6	**	453,0	574,0	413,0
SFR_G	***	1,1250	1,0200	1,2320	ns	0,8404	0,8020	0,8889
FLAV	**	0,0210	0,0315	0,1071	**	0,1552	0,1133	0,1914
ANTH_RG	*	-0,0490	-0,0348	-0,0330	**	0,2330	0,2056	0,2557

Statistical analysis (one-way ANOVA) of the effect of LED light on morphometric and fluorometric parameters in red and green genotypes of mustard and radish.
 SFR_G: chlorophyll content
 FLAV: Flavonols content
 ANTH_RG: antochyanins content



WORKING GROUP



The SOLE project: a plant greenhouse demonstrator for fresh food production in space – FISV congress 14-16 September 2022



E. Bennici¹, E. Benvenuto¹, M. Crisconio², A. Desiderio¹, E. Di Mascio³, Francesca Ferranti², M. Garegnani^{1,4}, L. Giuliani¹, L. Nardi¹, C. Pacelli², G. Pontetti², M. E. Villani¹

¹Dept for Sustainability, ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Casaccia Research Center, Rome, Italy

² Human Spaceflight and Scientific Research Unit, Italian Space Agency, Rome, Italy

³ G & A Engineering S.r.l, Oricola, AQ, Italy – now EltHub S.r.l. Oricola, AQ, Italy

⁴ Dept of Aerospace Science and Technology (DAER), Politecnico of Milano, Milan, Italy



XVI FISV Congress

**3R: Research, Resilience,
Reprise**

Reggia di Portici (Naples), Italy
14-16 September 2022



CONCLUSIONS



SOLE demonstrator allows to monitor and analyze data on plant growth and on the accumulation of bioactive metabolites in real time and remotely.

SOLE demonstrator can be easily adapted for space applications as growing plant on-board the International Space Station or in mini/micro satellites.

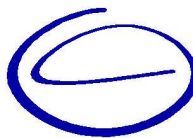
This biotechnological innovation ensures an improvement of the nutritional quality of the ready-to-eat product in future space missions.





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