PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE (PRIN) – Bando 2022 PNRR

Smart systems for improving artificial light use efficiency in controlled environment agriculture

SMART-LIGHT

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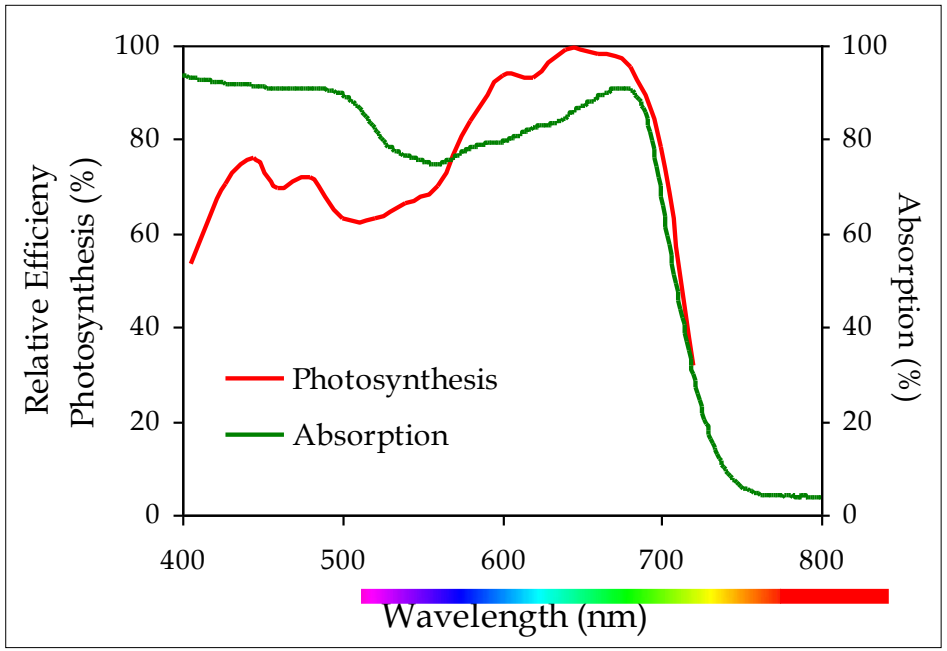
UNITO – Roberta Bulgari, Andrea Ertani

CNR – Simonetta Caira

CONTEXT

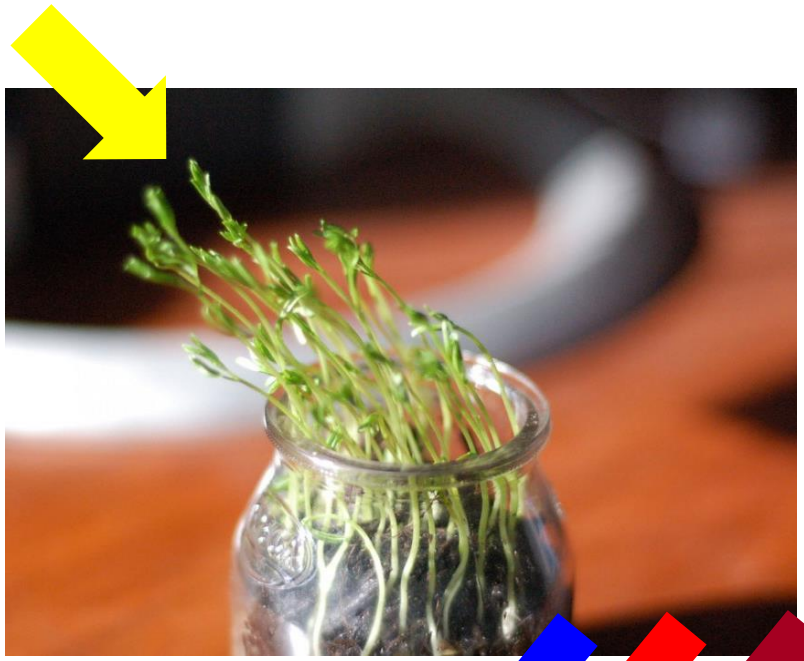
- Light quantity (intensity and duration) and quality (wavelength composition) affect plant behaviour in the entire life cycle, as plants use light as both energy source for photosynthesis and as a signal to regulate many other fundamental processes in photomorphogenesis.
- Providing sufficient light is one of the major technical challenges for the development of successful plant-production systems in controlled environment agriculture (CEA) and, more specifically, in indoor environment such as vertical farming (VF).

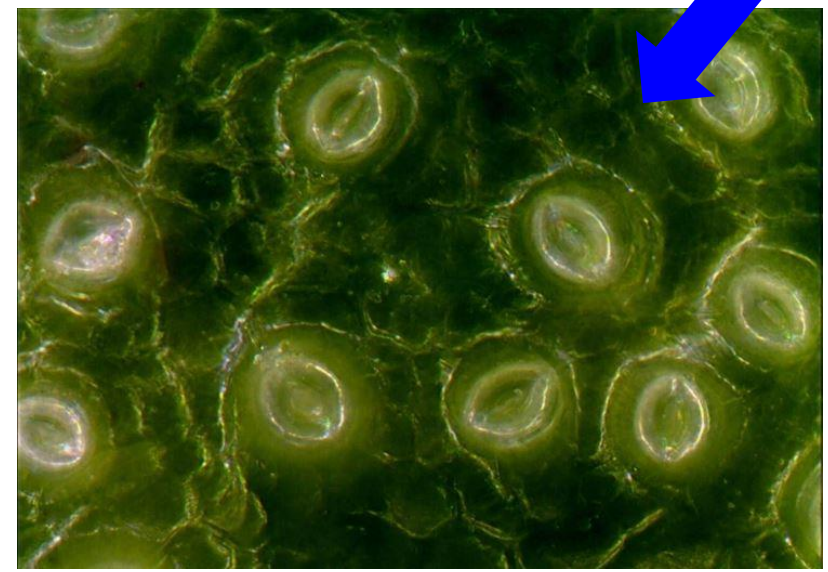
Photosynthesis



Photomorphogenesis

Wavelengths	Photoreceptors	Plant response
Red, Far-red (600-750 nm)	**PHYs**	Germination, De-etiolation, Shade avoidance, Inhibition of stem and petiole elongation, Leaf expansion and flattening, Circadian rhythms, Flowering, Branching
Green (530- 570 nm)	**CRYs**	De-etiolation, Inhibition of stem and petiole elongation, Leaf expansion, Circadian rhythms, Flowering, Flavonoid biosynthesis. Response to shade by B/G photoperception
Blue (450-500 nm)	**PHOTs**	Leaf flattening, Phototropism, Stomatal opening, Chloroplast relocation
UV-A (320-390 nm)	**ZTL/FKF1/LKP2**	Circadian rhythms, Flowering
UV-B (290-315 nm)	**UVR8**	De-etiolation, Flavonoid biosynthesis

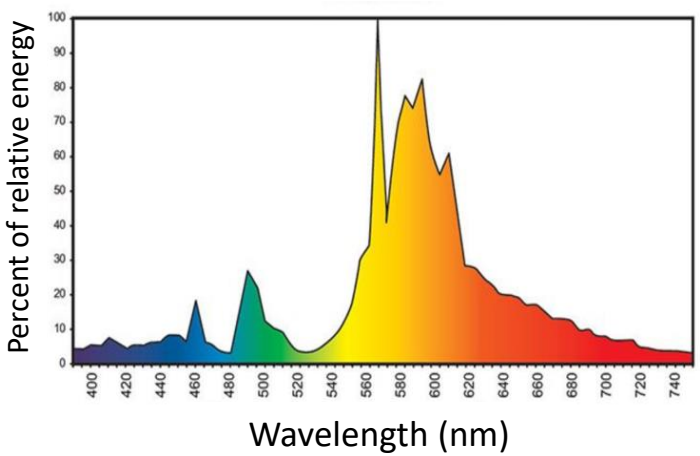




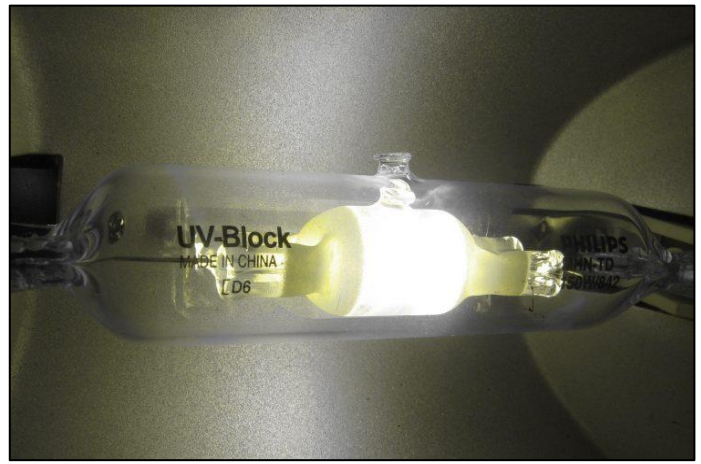
Light sources

High-Pressure Sodium (HPS)

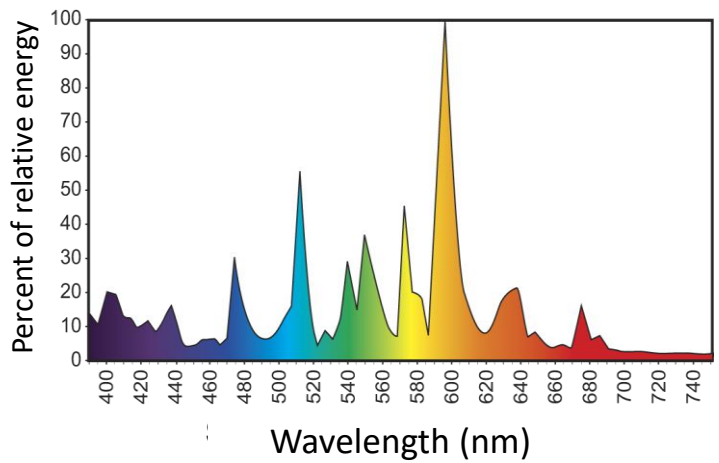
Eye Hortilux Super HPS
https://eyehortilux.com/grow-lights/super-hps/



Metal-Halide (MH)

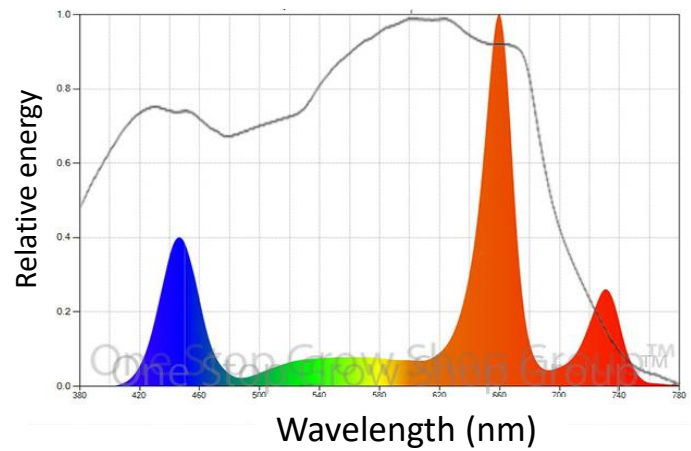


Eye Hortilux MH
https://eyehortilux.com/grow-lights/standard-metal-halide/



Light Emitting Diode (LED)

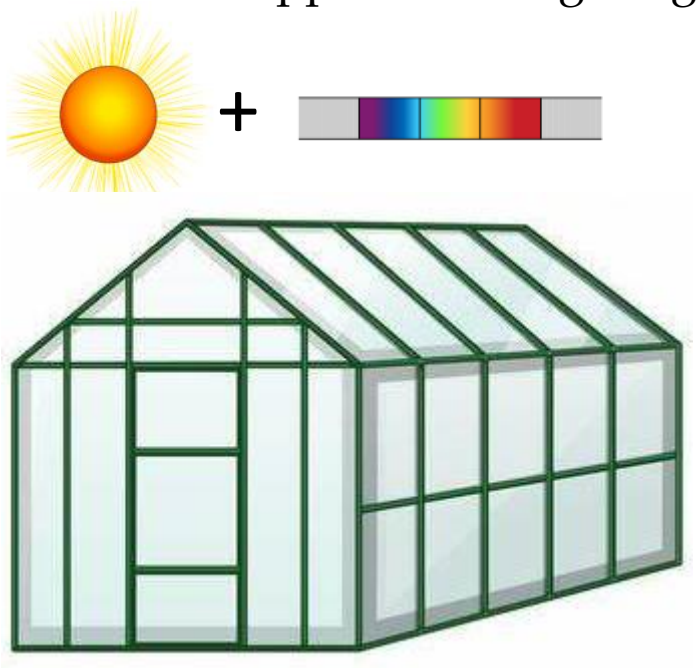
Heliospec LX601C
https://www.heliospectra.com/

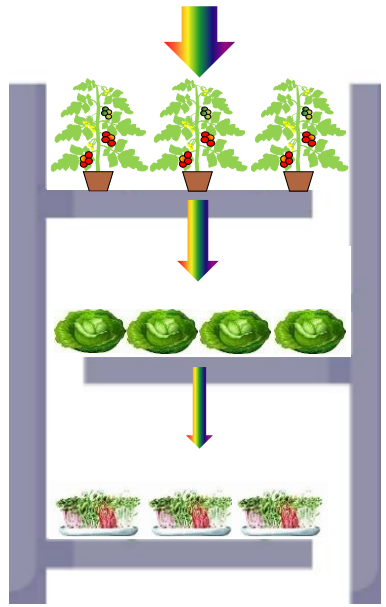


OBJECTIVE

To identify potential strategies to improve the profitably and the sustainability of cultivation of vegetables grown vertically in greenhouse and in indoor vertical farm.
In different type of crops (microgreens and leaf, fruit and tuber vegetables) with different light requirements, to optimize the use efficiency of LEDs as both integrative and sole light source, while increasing the soil use efficiency in greenhouse and the sustainability of vertical farming.

Greenhouse
LEDs for supplemental lighting





Vertical farm
LEDs as sole light source

Work packages (WPs) and interaction among the research activities

WP1 (leader UR1-UNINA)
Characterization of plant response
to changes in light intensity

WP3 (leader UR2-UNITO)
Characterization of plant response to different
red:blue (R:B) ratios compared to white light

WP2 (leader UR1-UNINA)
Evaluation of B-G-R supplemental light and
different positions of light sources and
identification of the best LED system configuration

WP4 (leader UR2-UNITO)
Definition of the best spectral composition of
LED light in vertical farm

WP5 (leader UR3-CNR)
Evaluation of the effects of light environment
on qualitative aspects, through a multi-omic approach

WP6 (All RUs)
Elucidation of the influence of light
on nutrient and nutraceutical composition

WP7 (leader UR1-UNINA)
Evaluation of economic sustainability of the proposed strategies

WP8 - Project management (UR1-UNINA)

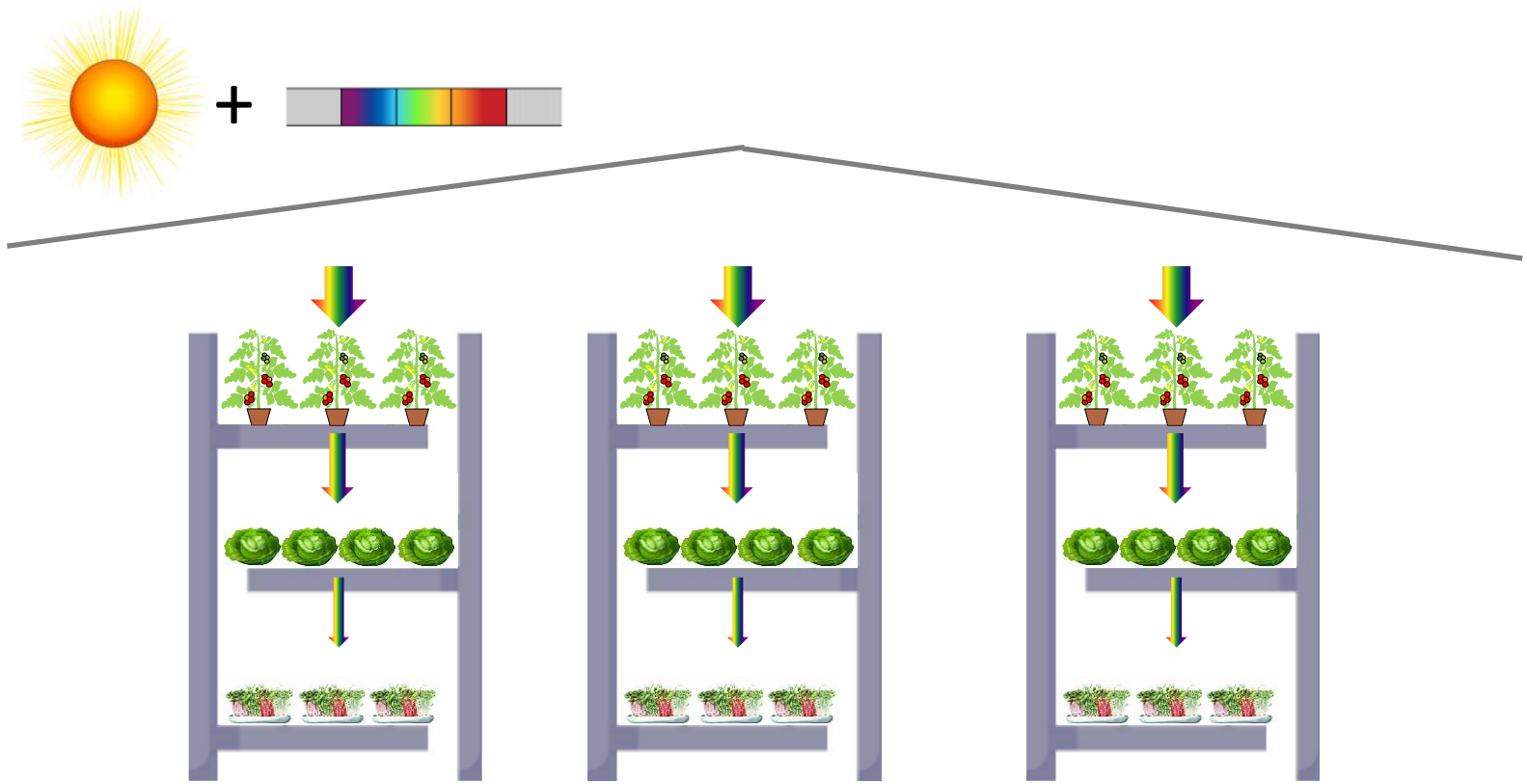
Time schedule of the research activities
(GANTT CHART)
SMART-LIGHT

	Task	Description	YEAR 1						YEAR 2					
			BIM 1	BIM 2	BIM 3	BIM 4	BIM 5	BIM 6	BIM 1	BIM 2	BIM 3	BIM 4	BIM 5	BIM 6
UNINA	**1.1**	Literature review on light requirements of the selected crops												
UNINA	**1.2**	Preliminary characterization of photosynthetic response to light intensity												
UNINA	**2.1**	Functional modulation of light intensity and LED system configuration (Greenhouse)												
UNINA	**2.2**	Results integration and validation												
UNITO	**3.1**	Literature review on light requirements of the selected crops												
UNITO	**3.2**	Preliminary evaluation of crop responses to the light treatments (Vertical farm)												
UNITO	**4.1**	Identification of the optimal R:B ratio in the light spectrum												
UNITO	**4.2**	Analytical determinations and data analysis												
CNR	**5.1**	Literature review on light quality effects on the metabolism												
CNR	**5.2**	Phytochemicals analysis by liquid chromatography HRMS												
CNR	**5.3**	Differential proteomic analysis												
ALL RUs	**6.1**	Elucidation of the influence of LED light on nutrient and nutraceutical composition												
UNINA	**7.1**	Evaluation of economic sustainability: Conceptual framework												
UNINA	**7.2**	Evaluation of economic sustainability: Analytical framework												

RU1 UNINA
Roberta Paradiso, Stefania De Pascale, Teresa Del Giudice, Nafiou Arouna

Objectives

In **greenhouse** cultivation of vegetables, to identify a possible strategy to improve the soil and light use efficiency, by means of a better distribution of plants, able to better exploit the available volume, and of LED sources, able to optimize the light interception by the canopy.



RU1 UNINA

WP1 - Characterization of the plant response to changes in light intensity (months 0-6)

Task 1.1 – Literature review on light requirements of the selected crops, in terms of light intensity and spectral composition, and on modulatory effects of light on both crop productivity and product quality achievable by LEDs application;

Task 1.2 – Preliminary characterization of photosynthetic response to light intensity and identification of the best fluence rate (**at single plant level**): light saturation curves will be built to identify the saturation PPFD and the range of light intensity for the maximum quantum yield of photosynthesis.

RU1 UNINA

WP2 - Evaluation of B-R LED supplemental light and different positions of light sources and identification of the best configuration of LED system (months 7-24)

Task 2.1 – Functional modulation of light intensity and system configuration for integrative LED lighting in greenhouse (at crop level)

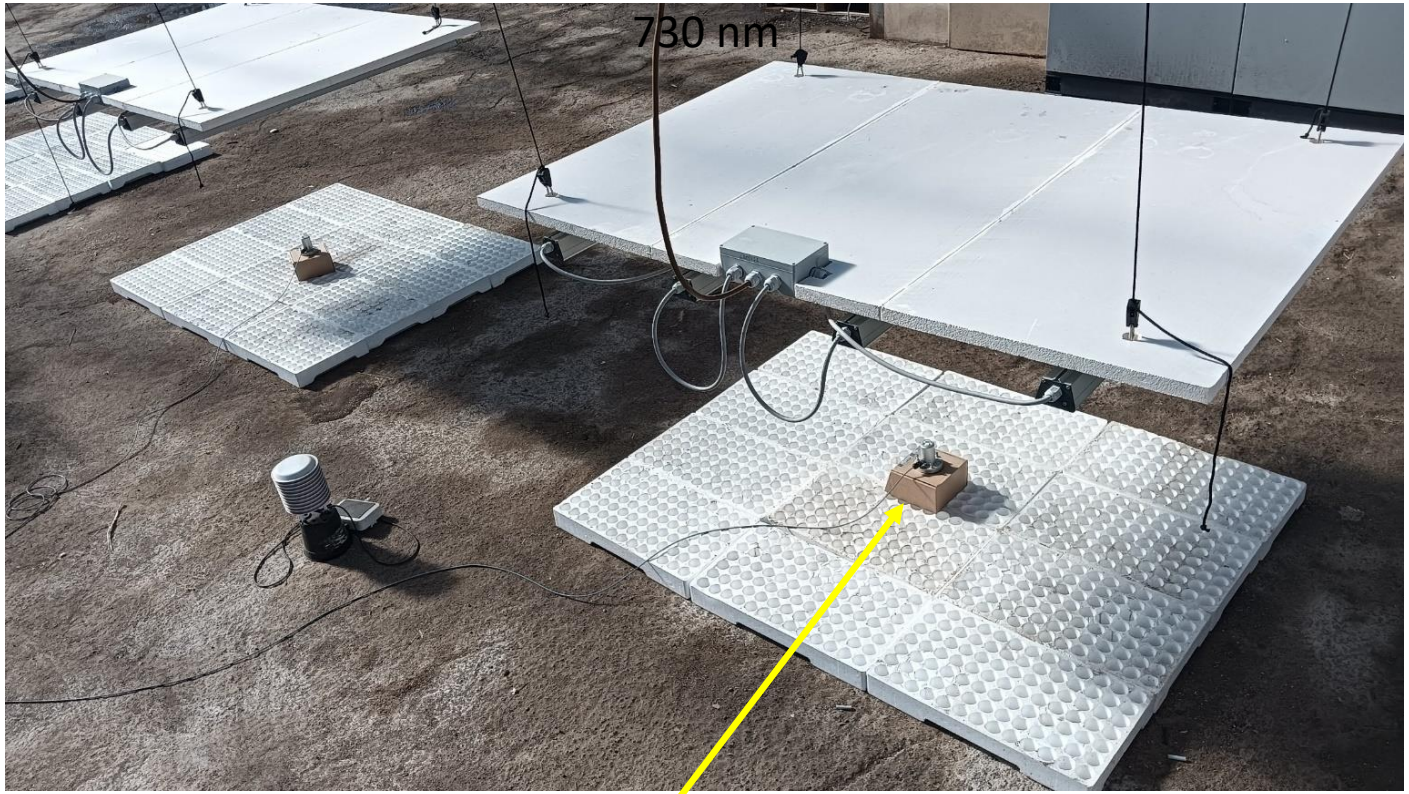
Supplemental LED light at the best B:R ratio will be provided to integrate the solar radiation in each layer at the optimal intensity for the different crops, comparing different positions of light sources, above the canopy (top lighting) and within the plant rows (interlighting).

Task 2.2 – Results integration and validation

The best lighting protocol for each species, in terms of intensity and spectrum, will be validated using to most efficient LED lamps positioning in the vertical system.

LED 4 channels: white 5000K, red 660 nm, blue 450 nm, far red 730 nm

730 nm



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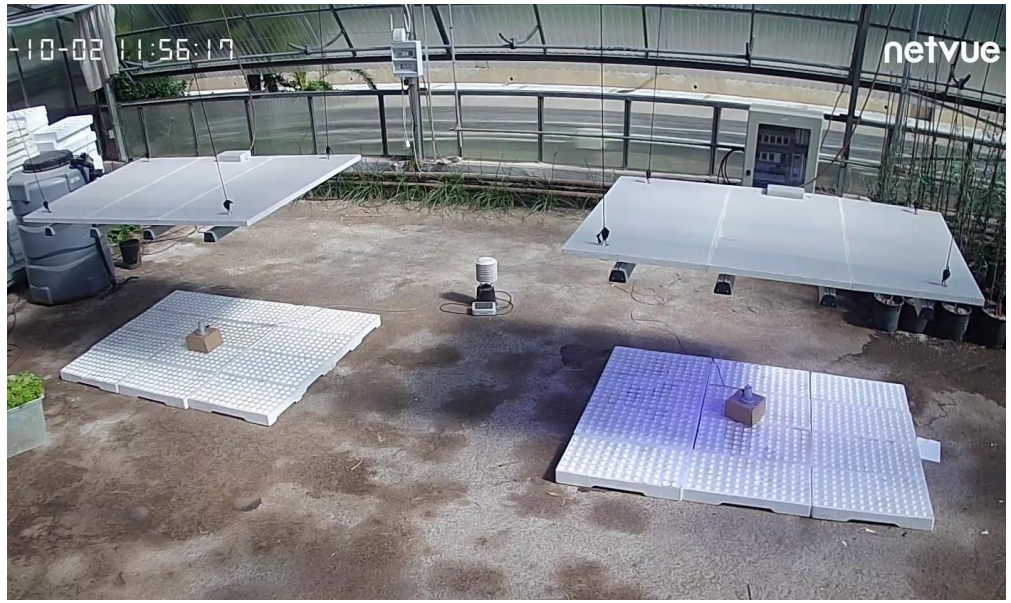
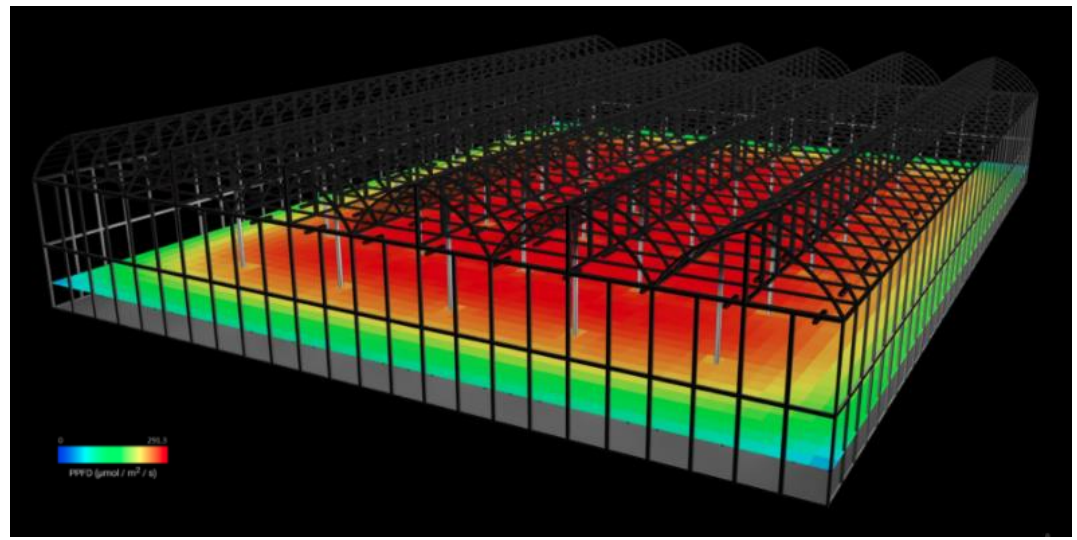
Sunlight Ray Trace Simulation





A study on the movements of the sun during the day and over the seasons, including the effects of the greenhouse architecture, to predict the effects at the crop level in terms of shading

RU1 UNINA

Two types of culture

- Tuberous plant (potato)
- Leafy vegetables (lettuce, kale, Swiss chard)

Two lighting treatments

- Integrative LED light (R:B 2:1)
- Natural light (Control)

Potted plants (5 L pots)

36 plants per lighting treatment (72 plants in total per species)

RU1 UNINA

Measurements and Analyses

Plant physiology

- Leaf greenness (SPAD), chlorophyll a fluorescence, gas exchanges

Plant growth and leaf yield and quality

- leaf area at different times and at the harvest
- number, fresh weight, dry weight, dry matter percentage of leaves/tubers, harvest index (potato), at the harvest
- chemical analysis of leaves: macro- and micro-nutrients, chlorophylls and carotenoids
- chemical analysis of tubers: macro- and micro-nutrients
- leaf quality: colour, vitamins, antioxidant activity, total ascorbic acid, polyphenols
- tuber quality: proteins, starch, dietary fiber, total ascorbic acid, polyphenols, glycoalkaloids
- metabolomic and proteomic analysis (S. Caira, CNR)

Economical sustainability

- cost/benefit analysis of the proposed lighting protocol (T. Del Giudice, UNINA)

WP7 - Evaluation of economic sustainability of the proposed strategies

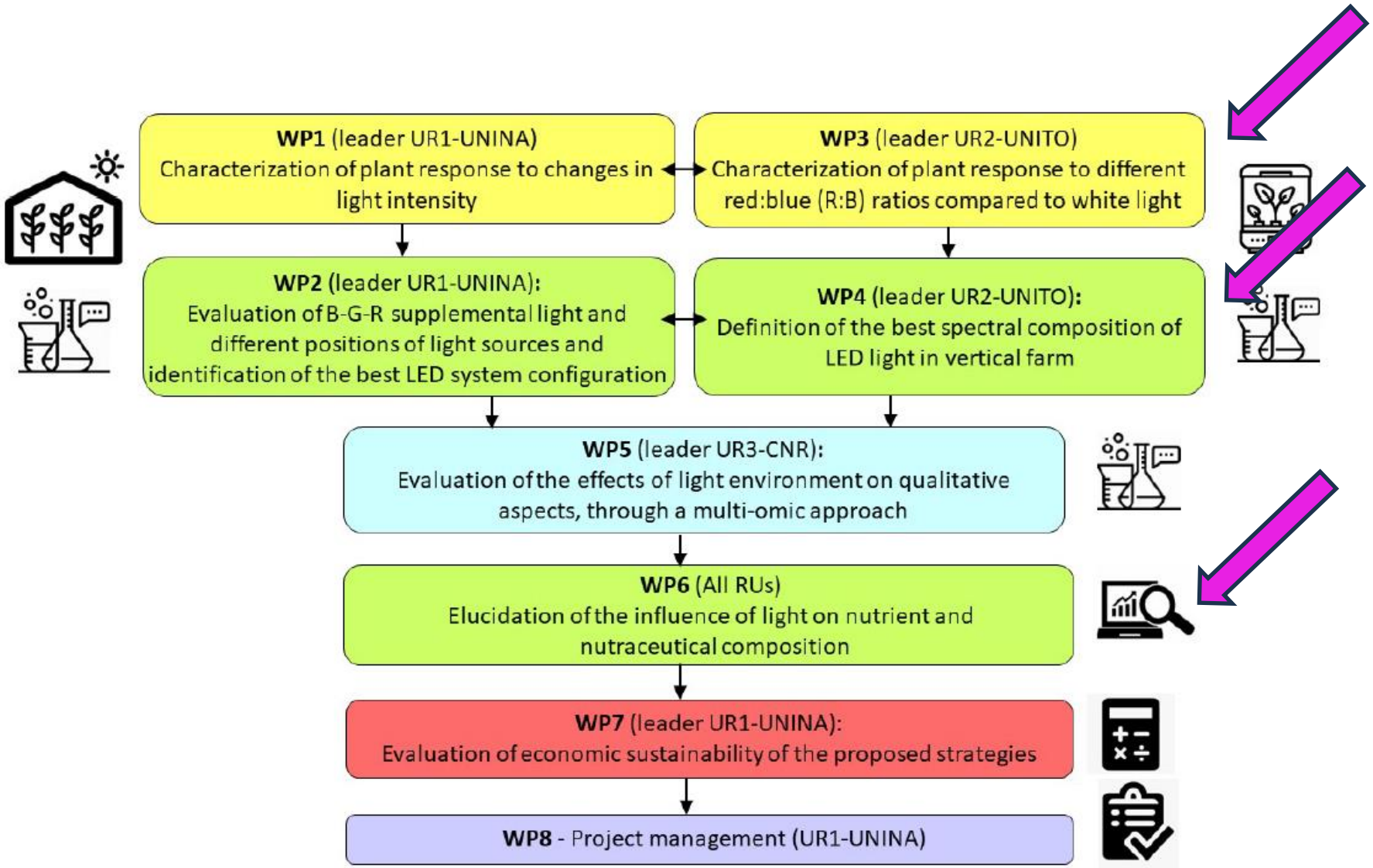
Task 7.1 – Conceptual framework

Systematic literature review focused on added costs and cost-benefit analysis of the proposed protocols for greenhouse and vertical farm application (i.e., yield increase and price point needed for new protocols integration).

Task 7.2: Analytical framework

The process flow diagram and main outputs of the two vertical farming systems will be identified based on the experimental protocols and results of WP1, 2, 3, and 4. Comparison of economic results and the evaluation of viability to activate one or both the production lines will be investigated. A costs/benefits analysis on realization and operative costs and production outputs, and assessment of the economic sustainability of the proposed strategies will be presented at month 24.

RU2 UNITO – Roberta Bulgari (RtdA), Andrea Ertani (Associate Professor)



RU2 UNITO

- The **objective** of the UNITO unit's activities will be define the optimal environmental and agronomic condition, in soilless cultivation systems, for **cress microgreens, baby leaf lettuce, and tomato**, grown under different **LED light treatments, focusing on red (R), blue (B), and white (W)** LED light source. The optimal cultivation protocols will also aim to improve the light use efficiency, and therefore reduce the related energy costs, in vertical farming. The next step will be to transfer the acquired knowledge, also to other cultivation systems in a protected environment.

- **Plant cultivation**
  Microgreens will be grown in a soilless cultivation system, on a substrate mat (hemp). Hemp was chosen with a view to enhancing local products, linked to the territory. Baby leaf lettuce will be cultivated in a hydroponic system, while aeroponics will be used for tomato. The cultivation of the selected species will take place in a totally conditioned growth chamber equipped with a LED-based illumination system and with hydroponics and aeroponics systems.

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RU2 UNITO

WP3 - Study of the plant response to different R:B ratios compared to white light (months 0-6)

Task 3.1 – Literature review on the light requirements (light quality) of the three selected crops, grown under artificial light only. In particular, the effects of red and blue light will be examined.

Task 3.2 – Preliminary evaluation of crop responses to the light treatments. The preliminary tests will be carried out to investigate the effects of different R:B ratios compared to white light on plants (2 conditions x 3 species). For microgreens, lettuce, and tomato three different cultivation protocols will be established, considering the specific needs of each species and also in the light of the information found in the literature.

RU2 UNITO

WP4 - Identification of the best configuration of LED system and analysis of the obtained results (months 7-24)

Task 4.1 - Identification of the optimal R:B ratio in the light spectrum. Once the optimal cultivation protocols have been identified for each species, at least one cultivation cycle will be repeated to validate the data observed in the preliminary tests and transfer them also to greenhouse application (in cooperation with RU1-UNINA).

Task 4.2 – Analytical determinations and data analysis. At harvest, detailed *in vivo* and destructive determinations will be performed, focusing on production, nutritional and nutraceutical quality of vegetables. In addition to these analysis, frozen samples will be sent to RU3-CNR, on dry ice, for metabolomic and proteomic analyses, to deepen the effect of light on target molecules.

RU2 UNITO

- **Quality and physiological analytical determinations**
  A characterization of fresh vegetables products and quality attributes will be performed by the R2-UNITO research group through physical and chemical methods.

yield
biomass
growing cycle length
chlorophyll *a* fluorescence
net photosynthesis
stomatal conductivity
photosynthetic water use efficiency (pWUE)
nutrient use efficiency (NUE) (by ICP-MS)
sugars
nitrate
phenolic index and anthocyanins
chlorophylls and carotenoids
ascorbic and dehydroascorbic acid (by HPLC)

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RU2 UNITO

WP6 - Elucidation of the influence of light on nutrient and nutraceutical composition

Elucidation of the influence of light intensity, orientation and spectrum of LED lighting from both greenhouse and vertical farm cultivation, in terms of nutrient and nutraceutical composition.
This WP will be realised by all the RUs, each for its specific expertise and equipment.

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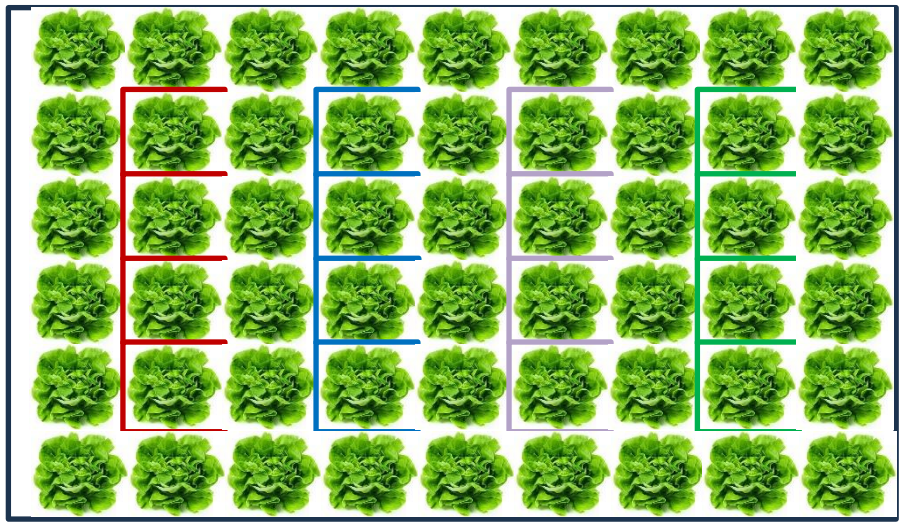
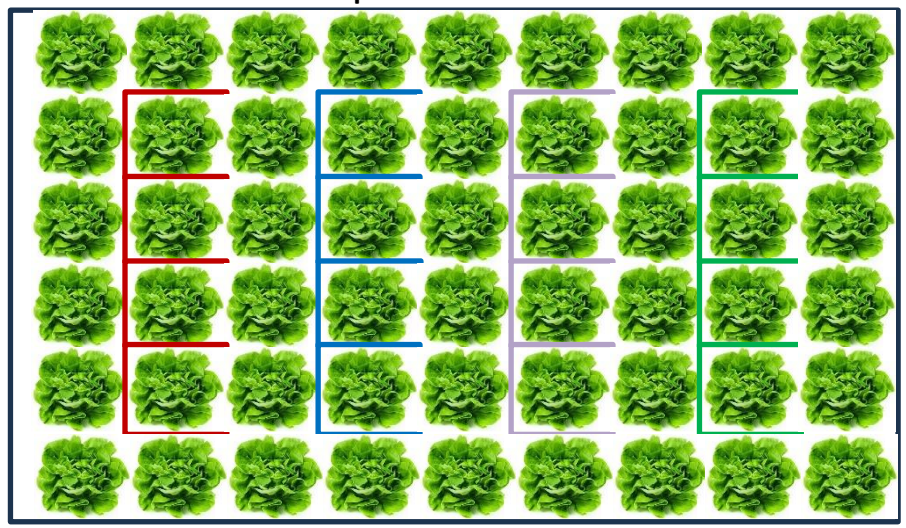
Controllo

1° replicato 2° replicato 3° replicato 4° replicato



Trattato

1° replicato 2° replicato 3° replicato 4° replicato



N2 liquido

Liofilizzazione

Campione in polvere

Controllo				Trattato			
1° replicato	2° replicato	3° replicato	4° replicato	1° replicato	2° replicato	3° replicato	4° replicato

ANALISI PROTEOMICA DIFFERENZIALE QUANTITATIVA

mediante spettrometria di massa basata sul tag di massa tandem (TMT)
è in grado di valutare le differenze tra i livelli di espressione delle proteine estratte dalle piante di lattuga cresciute in condizioni diverse

Estrazione proteine mediante precipitazione in fenolo

ANALISI METABOLOMICA TARGETED

Fornirà un'istantanea degli effetti di modulazione della qualità della luce mediante caratterizzazione di biomarcatori fitochimici specifici della qualità della specie scelta come acidi fenolici, polifenoli o alchifenoli insieme ad amminoacidi, loro derivati e oligosaccaridi ramificati (cioè galattomannani, arabinoxilani, frutto-oligosaccaridi, galatto-oligosaccaridi).

Estrazione metaboliti in soluzione MetOH: H2O 4:1

Grazie dell'attenzione!

SMART-LIGHT