Applications of LED Lighting Systems in Horticulture

"There's more to light"

Dr. S. Krishna Kumar

Associate Research Scientist

Desert Agriculture and Ecosystems Program

Environment and Life Sciences Research Centre

Kuwait Institute for Scientific Research

Kuwait

Benefits of solid-state LED lighting to the horticulture industry

- Increased yields
- Earlier flowering
- Faster root growth/germination
- Better control of plant growth
- More economical use of space
- Also highly energy-efficient
- Helps horticultural producers to lower electricity consumption
- Especially during the high consumption periods of autumn & winter

Use of LEDs in different segments of Horticulture

Vegetable production

Tissue culture and young plant production

Cut flowers

Seedlings and nurseries

Companies develop lighting systems for horticulture by having a R&D team consisting of plant physiologists and technical engineers who have been trained in the key horticultural countries to provide full support to growers and breeders.

Light Manufacturing Industry — Academic Research Collaboration

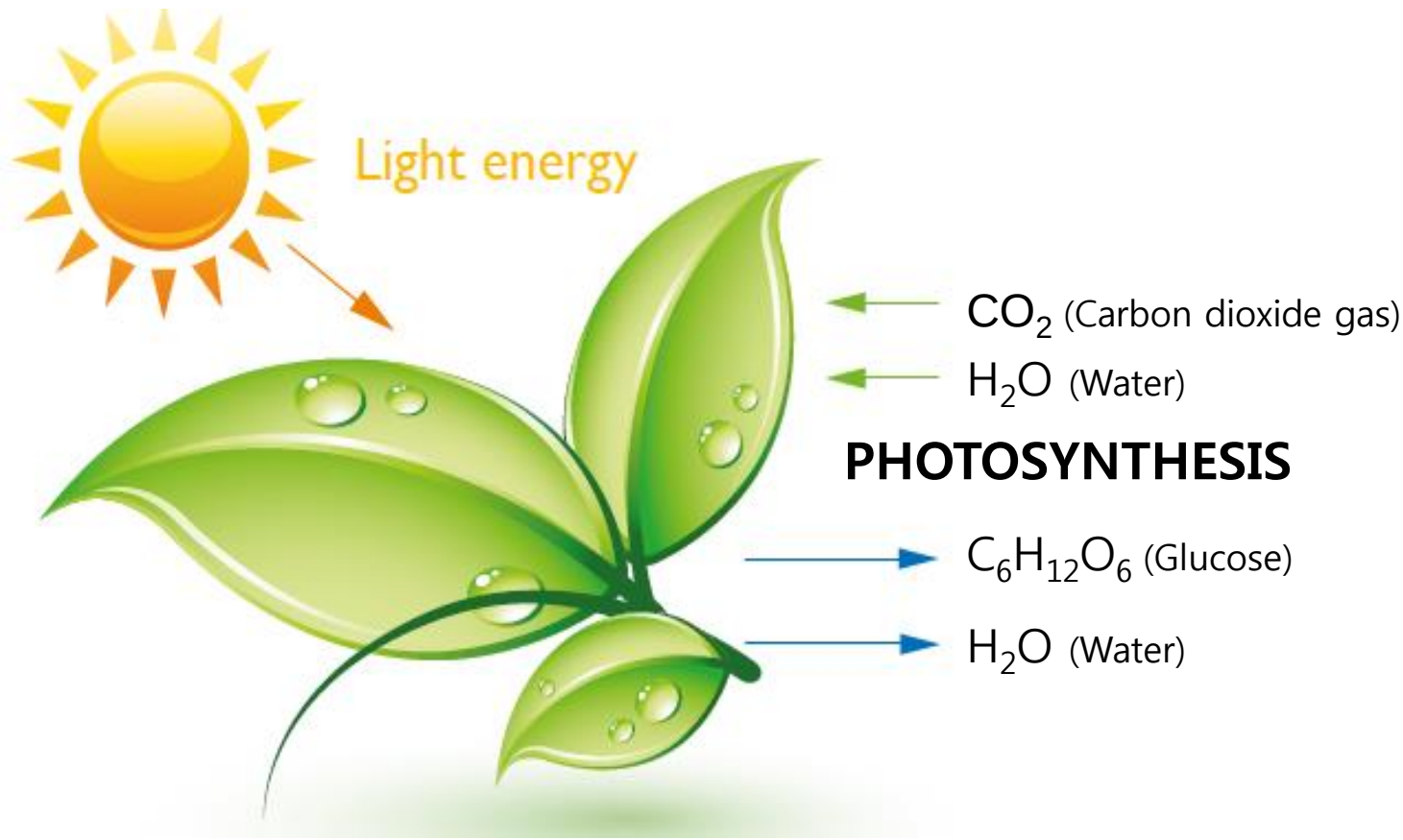
- A light recipe is an instruction based on knowledge of how to use light to grow a certain crop under certain conditions
- A light recipe indicates:
  - ✓ Lighting aspects: light level, spectrum, required uniformity, position and time
  - ✓ Parameters for which the recipe is valid, e.g. climate conditions
  - ✓ Expected results besides energy saving

Contd…

- Close contact with commercial growers, breeders, universities and research institutes
- Own laboratories and test stations
- Independent research and field testing
- In 1995 – Philips – developed High Pressure Sodium lamp specially designed for greenhouses
- In 2008 Philips introduced first horticulture GreenPower LED solution to the market
- Today, the LED range has been extended to a complete family comprising multiple solutions
- Besides stable and reliable quality, they display characteristics including long life, low light fading, high waterproof and dustproof factors
- Field tests with growers have gained a deep understanding of the light required by various plants at different growth phases
- Ultimate result - Greater control over growing conditions and the growth process, better results, and higher yield

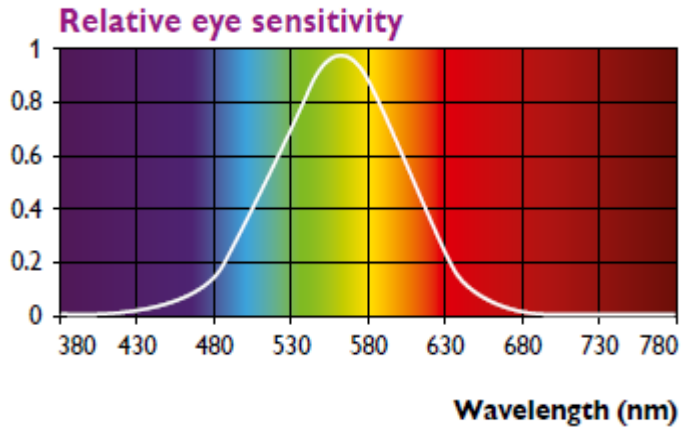
Light & plant growth

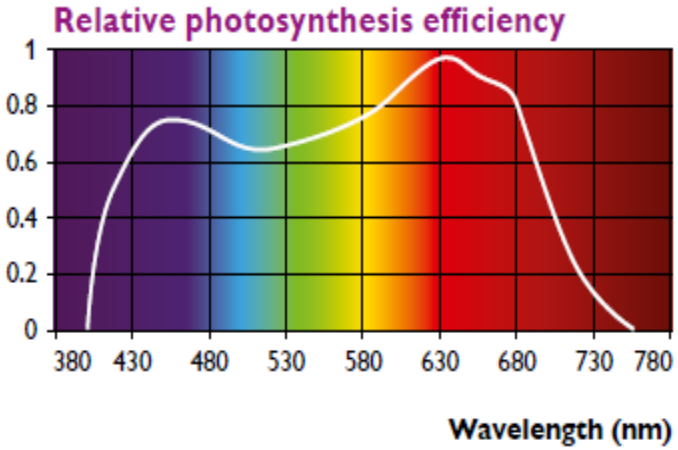
- Light – essential for plant growth
- Natural sunlight – cheapest source, but not available in sufficient quantities
- Artificial light necessary – Increased production and quality
- Plants have different sensitivity to light colors
- Plant growth - Light is defined in terms of small particles, also called photons or quantum
- The energy content of photons varies, depending on wavelength (light color spectrum)
- For one optical energy, almost one and a half as many red photons can be produced compared with blue
- This means that often red light sources produce more efficient light photons than a blue light sources
- Plant has also various sensitivity for various colors of light, and that influences different light-sensitive activities



- **Global radiation spectrum used by a plant for its photosynthesis is between 400-700 nm**
- **PAR-light (Photosynthetically Active Radiation)**
- **Amount of photons in the PAR region are called growth light (indicated in micromol (µmol)**
- **So, around 45% of global radiation is PAR light**

- Efficient lamp for plant growth must convert as much electrical energy as possible into PAR energy
- 'Daily light integral' (DLI) refers to the number of light particles, or photons, received during one day in the PAR region (400-700 nm)
- DLI specifically refers to the amount of photosynthetic light received in an area of 1 square meter each day
- The DLI can have a profound effect on root and shoot growth of seedling plugs, root development of cuttings, and finish plant quality attributes such as stem thickness, plant branching and flower number
- Propagation of cuttings 4-6 $mol.m^{-2}.day^{-1}$ is recommended, and for most bedding plants, perennials and potted crops at least 10-12 $mol.m^{-2}.day^{-1}$ is recommended





DLI – Measurements and Calculation

- DLI is measured in mol/m^2/day, which means the **number of moles of light (mol) per square meter (m^2) per day**
- What is a mole of light? A **mole is a very large constant number** (6.022 x 10^{23}, which equals 602,200,000,000,000,000,000,000)

What DLI is needed to grow high-quality transplants and finish plants?

- **The answer depends on the crop, but a common target minimum DLI inside a greenhouse is 10-12 mol.m^{-2}.day^{-1}**
- **Plant quality generally increases as the average DLI increases**
- **In particular, as the DLI increases, branching, rooting, stem thickness and flower number increase, and sometimes plant height decreases**
- **Some exceptions: shade crops such as African violets and Phalaenopsis orchids grow well under an average DLI of 4-6 mol.m^{-2}.day^{-1}**
- **Some crops flower earlier when grown under a high DLI compared to a low DLI**

Example calculation

DLI = average light intensity in µmol/m^2/s

µmol/m^2/s x hrs x 3600 : 1.000.000 = ... mol/m^2/day

200 x 14 x 3600 : 1.000.000 = 10 mol/m^2/day

Properties of light that make the plant grow well/flower

- **Light quantity / intensity**
  Total number of photons that it absorbs in the PAR region

- **Day length**
  Photoperiod

- **Spectrum**
  Mix of colors in the light (spectrum)

- **Light uniformity**
  Artificial lighting, uniformity and constant quality of light spectrum - Important for a constant quality of crop production

APPLICATIONS OF LED IN HORTICULTURE

Potted, bedding and young plants in greenhouse/climate chambers

- Provides a safe and reliable supplement or replacement to natural light
- Improves the quality of seeding and cultivates healthy seedlings
- Adjustable and controllable photoperiod to control the vegetative and reproductive growth of plants
- Fully utilizes greenhouse space and the production transportation line
- Effective heat management

Young plants (tissue culture, seedlings, cuttings)

- Due to high luminous efficiency, high-power fluorescent lamps can be replaced
- Maintains uniformity of illumination and reduces distance between layers
- Light recipe achieves higher quality to fulfill plant growth needs
- Improves high-quality seeding rate and shortens the production cycle
- Effective heat management saves on air conditioning costs and extends the service life of the electrical system

City farms (leafy vegetables and herbs)

- With high and stable yields, reduces production costs and continuously stabilizes supply
- Improves quality, nutrient content and flavor
- Shortens delivery time and provides fresh vegetables from a local supply
- Improves land use rate and increases the yield per unit area by multilayer cultivation
- Energy savings

Vegetable production in greenhouse

- High wire vegetable production (cucumber and tomato) with interlighting
- Effectively complements natural light with a spectrum and light intensity combination designed to promote plant growth
- Stabilizes and improves plant quality and yield, enabling growers to increase their profits
- The scientifically designed illumination angle and light position allow plants to make maximum use of the light
- Interlighting among vegetables and flowers, by utilizing the low-heat characteristic of LED, to increase production
- Efficient use of energy can effectively reduce the electrical system load and energy costs

Benefits of LEDs

- **LED lighting, the growth light – spectral output – can be tuned**
- **Possible to apply the optimum 'light recipe' at every stage of a crop's growth**
- **Effective heat management, long lifetime, high luminous efficiency and energy efficiency, opens up tremendous opportunities for growers and breeders**
- **Commercial horticulture market – Increased yield, early flowering, faster (root) growth, and more economical use of space**

LED lighting - New opportunities to horticulture

- **Light spectrum**
  Provides the best 'light recipe' at each growth phase
- **Light intensity**
  Provides the illumination intensity that crops need
- **Effective heat management**
  Enables greater control over the climate in the greenhouse or climate chamber and reduces the need for cooling
- **High luminous efficiency**
  As LEDs produce only a little radiant heat, it is possible to position the light source close to the crop without burning the leaves
- **Long lifetime**
  Reduces the need to replace lamps
- **Energy efficiency**
  Lowers energy costs and helps protect the environment
- **Robust**
  Dustproof and moisture-proof, and no risk of glass in your crops
- **Optical design freedom**
  Since a LED is only a micro-chip, it fits easily into any application and can increase uniformity

Protected Horticulture

Research interests

- Plant factory (growth and development on vegetable affected by light quality, photoperiod in closed plant production system)
- Development for medium and photo-selective shade agent (new medium & white shade agents development for hydroponic cultivation)
- Environmental condition (temp., RH, light, CO_2 …) control in the greenhouse
- Plug seedling production and systemization

Priority Areas

Greenhouse Environment Control

- Light, temperature, water, CO_2, air flow, etc.

Plant Factory

- Plant growth control by LED light and CO_2

Hydroponic technology

- Vegetables and fruits
- Development of medium

Greenhouse summer temperature reduction

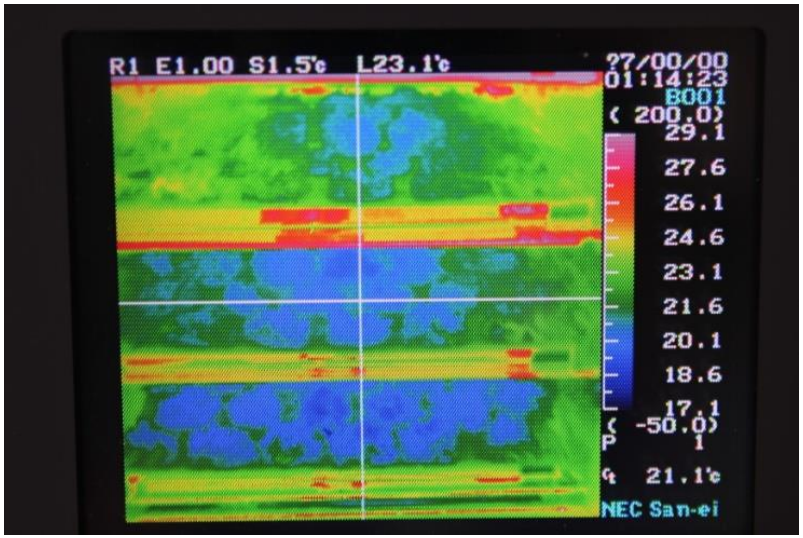
- Development and testing of Shading agents

Research infrastructure

Closed type plant production system

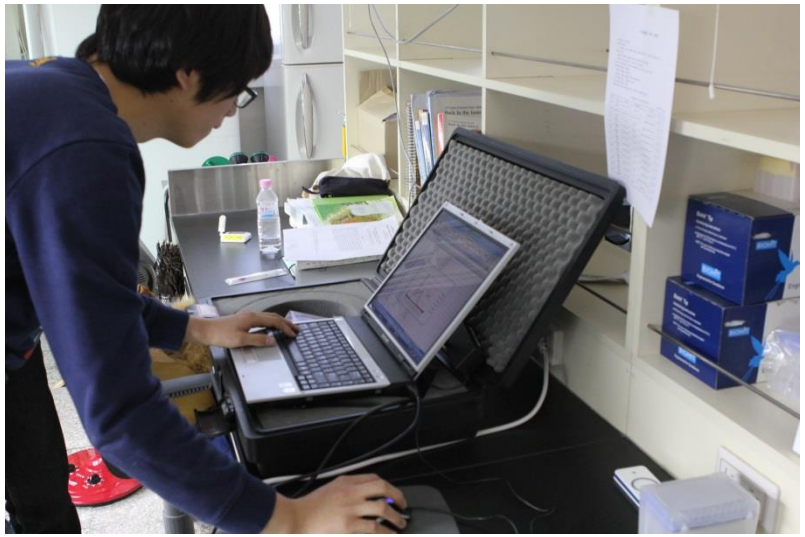
Closed type plant production system

LI-6400, LI-COR, USA



Thermal image analyzer (NEC THB100MR, San-ei Instruments, Ltd., Japan)

Chlorophyll fluorescence (PAM-200, Walz, Effeltrich, Germany)

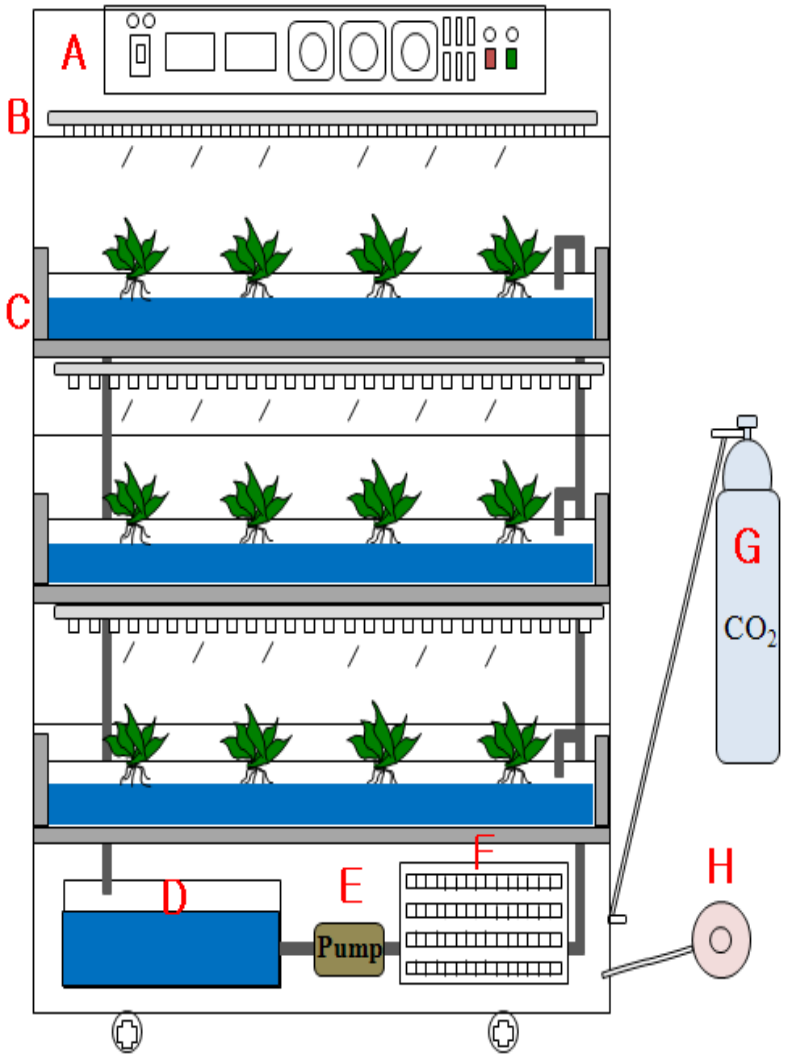


ILT 900, International Light Tech. Co. Ltd., USA

Venlo-type glasshouse and hydroponic cultivation system

Container type plant factory system

Research on the influence of LED light in closed-type plant factory



Schematic diagram of a recirculating ebb & flow hydroponic system in the plant factory. A; control system, B; artificial light sources, C; recirculating ebb & flow hydroponic system, D; tank E; pump, F; cooling system, G; CO_2 supplier, H; slidacs.

First study – Experimental results

Table 1. Power consumption for different light sources in plant factory system.

Light source	Electrical energy calculation	Electrical energy (W)
White LED #1(FC Poibe)	80V x 2.46A x 2=	393
White LED #2(Hepas)	205V x 1.36A x 2=	557
Fluorescent Lamp(Philips)	210V x 2.02A x 2=	848

- **The electrical energy consumed was 848 W by FL light source and it was only 393W consumed by WL #1 light source. This proved an energy saving of two times upon usage of White LED #1.**

First study – Experimental results (Contd.)

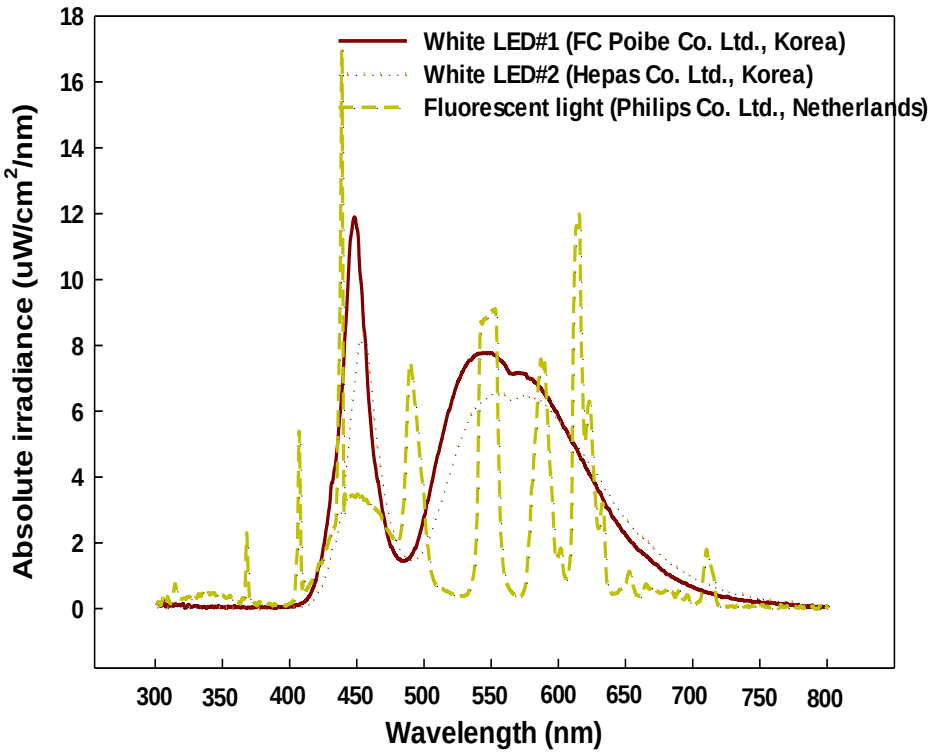


Fig. 1. Spectral distribution of the different light sources used in a closed plant factory. The light sources used were White LED#1(FC Poibe Co. Ltd., Korea), White LED#2(Hepas Co. Ltd., Korea), Fluorescent light(Philips Co. Ltd., Netherlands).

- **Heating problem was resolved upon use of LED when compared with fluorescent lamps**
- **White LED wavelength peak distribution was in the range of 450 nm and 550 nm, whereas Fluorescent lamps had a peak range of 450, 550, and 620 nm. LED light has a wider range than FL**
- **Second year study was done based on designing LED with respect to the fluorescent light wavelength spectrum**

First study – Experimental results (Contd.)

Photo. 1. Effect of light source & photoperiod on growth & development of lettuce grown in a closed-type plant production system

- **Plant height, length of the longest root, and fresh/dry weight - FL treatment produced best growth results**
- **Fluorescent light had many peak wavelengths when compared to LED**
- **To maximize the efficiency of photosynthesis, the various wavelength bands were explored based on a combination of LEDs**

First study – Experimental results (Contd.)

Table 2. Effect of light source & photoperiod on growth & development of lettuce grown in a closed-type plant production

Light source[z]	Photoperiod (Light/Dark)	Plant height (cm)	Length of the longest root (cm)	Fresh weight (g)		Dry weight (g)	
				shoot	root	Shoot	root
WL #1	12/12	14.9 f[y]	32.0 b	22.6 d	2.0 c	0.8 d	0.07 d
	18/6	15.8 d-f	32.5 ab	31.1 c	3.4 b	1.3 c	0.11 c
	24/0	17.9 bc	26.3 c	40.1 b	3.5 b	1.8 b	0.19 a
WL #2	12/12	15.2 ef	27.7 c	21.7 de	1.8 c	0.9 d	0.07 d
	18/6	16.2 de	31.7 b	38.9 b	4.3 a	1.7 b	0.13 bc
	24/0	18.1 b	31.8 b	47.6 a	4.6 a	2.2 a	0.19 a
FL	12/12	15.2 ef	35.0 ab	17.4 e	1.5 c	0.8 d	0.05 d
	18/6	18.1 b	36.0 a	30.9 c	3.0 b	1.5 c	0.12 c
	24/0	20.8 a	33.8 ab	52.3 a	4.6 a	2.2 a	0.16 b

[z] The light sources are WL #1, white LED (Hepas Co. Ltd., Korea); WL #2, white LED (FC Poibe Co. Ltd., Korea); and FL, fluorescent lamp (Philips Co. Ltd., the Netherlands).
[y] Mean separation within columns by 5% DMRT.

- Plant height, length of the longest root, fresh weight, dry weight were obtained in the FL with photoperiods of 24/0.
- Speculate that the poor growth results obtained in LED when compared to FL is due the low peak wavelength and absence of wavelength band at 660 nm.

First study – Experimental results (Contd.)

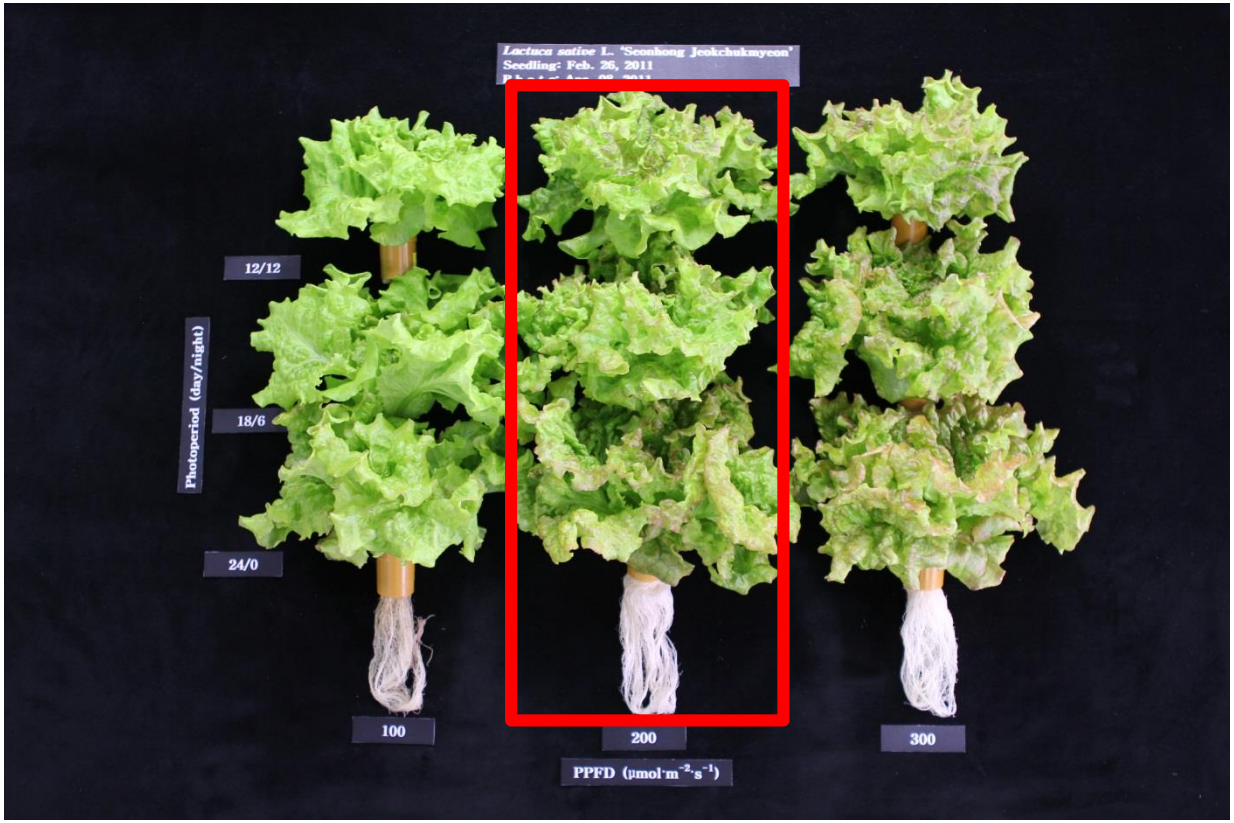


Photo. 2. Effect of light intensity & photoperiod on growth & development of lettuce grown in a closed-type plant production.

- **Best growth results at 200 PPFD and 24/0 (Light/Dark)**
- **Optimized light intensity was chosen and second set of experiments performed for specific PPFD**

First study – Experimental results (Contd.)

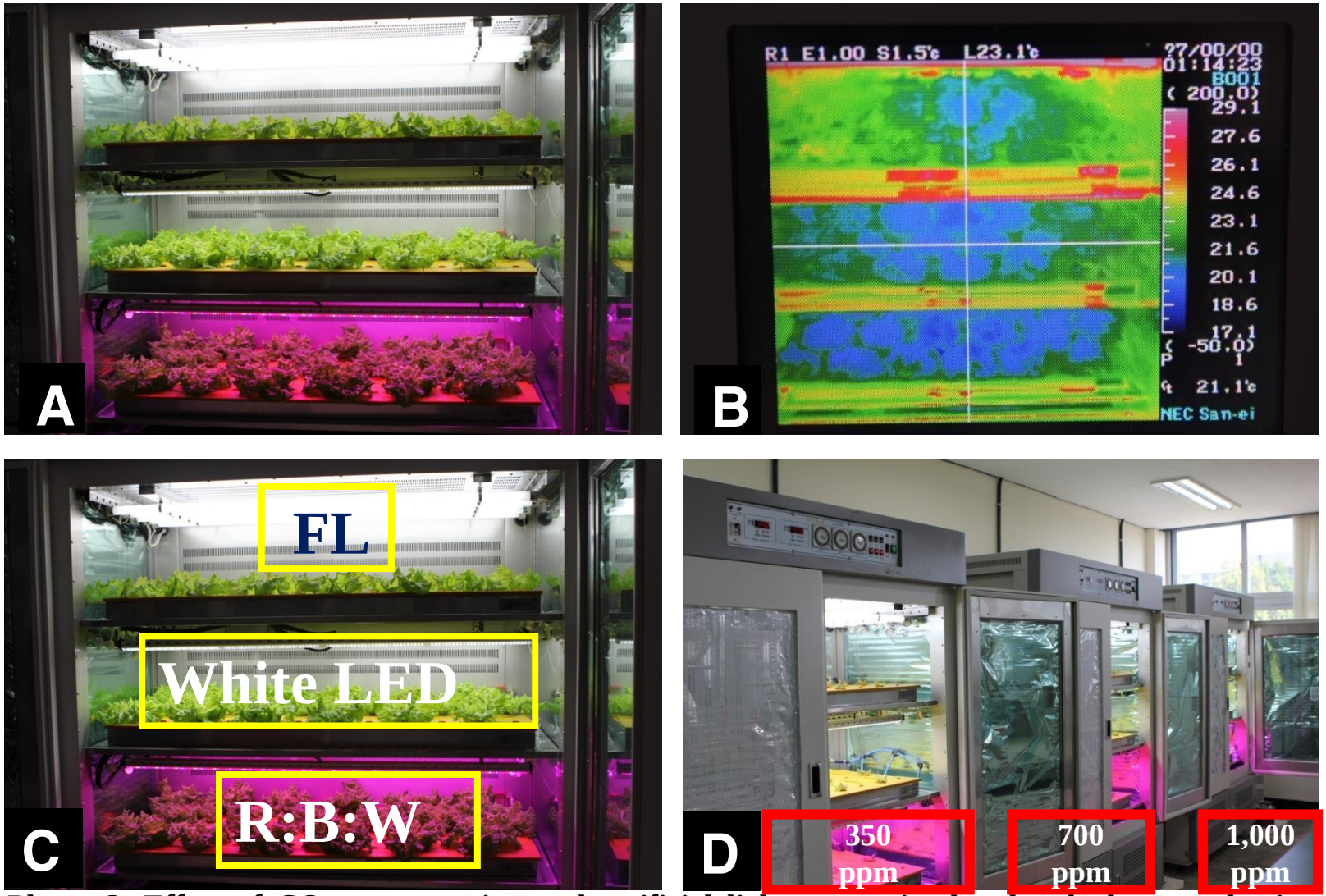


Photo. 3. Effect of CO_2 concentration and artificial light source in the closed plant production system. A, Plants inside the closed plant factory chamber; B, Thermal analysis; C, Artificial light source arrangement; & D, CO_2 supply arrangement.

First study – Experimental results (Contd.)

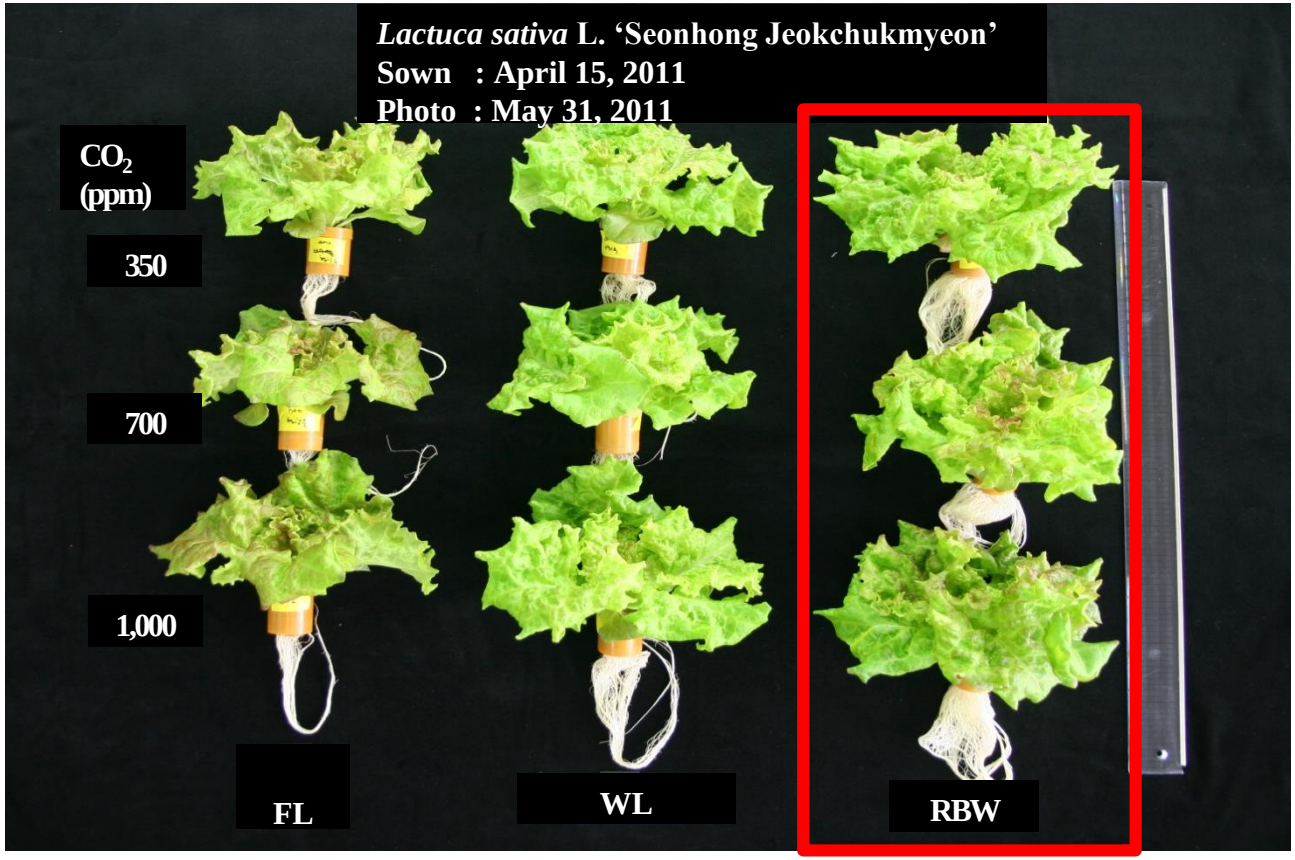


Photo. 4. Effect of light source & duration and concentration of CO_2 supply on growth & development of lettuce grown in a closed-type plant production system.

- **CO_2 concentration at 700 μmol·mol^{-1} produced more favorable growth**
- **RBW light quality showed greatest leaf area, fresh/dry weight, length of the longest root, etc.**

Second study – Experimental results

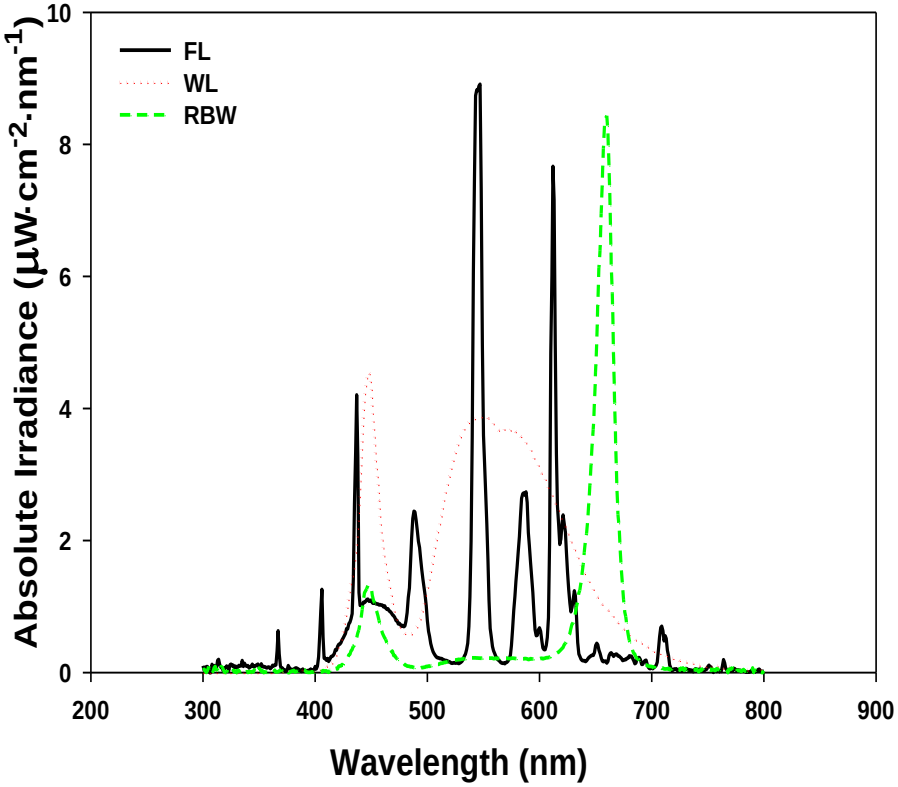


Fig. 1. Spectral distribution of the different light sources used in a closed plant factory. The light sources used were FL, fluorescent lamp; WL, white LED; & RBW, red:blue:white = 8:1:1 LED.

- **LED (red:blue:white=8:1:1) combination of 450 nm(blue) & 660 nm (red) wavelengths were optimal for increased photosynthetic efficiency of the plants**
- **Lettuce grown under RBW combination resulted in good plant size, leaf width, & leaf area whereas below-ground growth results were better in fluorescent light treatment**
- **CO_2 : 1,000 ppm & 24 hours photoperiod gave best results**

Second study – Experimental results (Contd.)

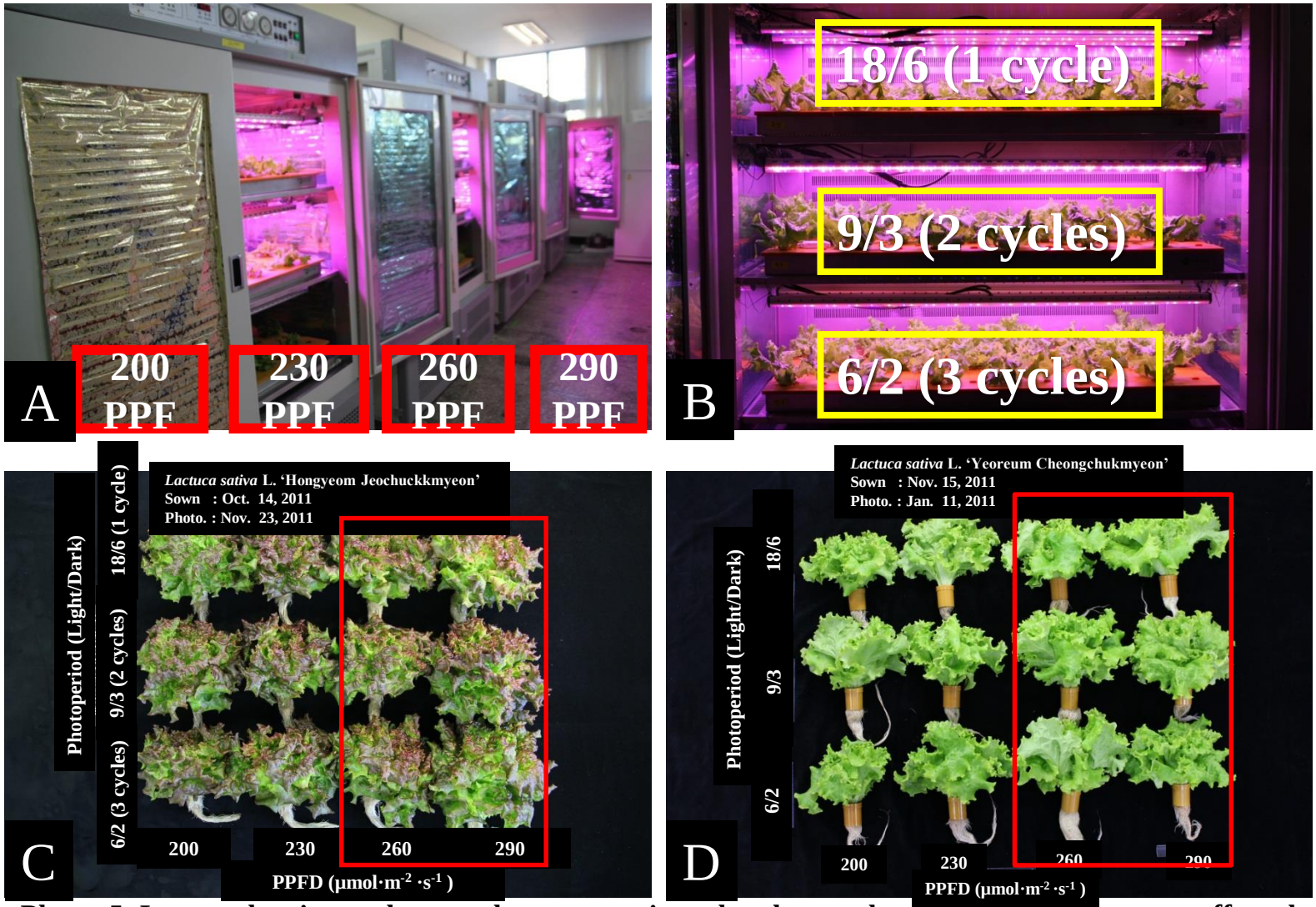


Photo. 5. Images showing on lettuce plants grown in a closed-type plant production system as affected by light intensity & photoperiod. A, Light intensity exp. ; B, Photoperiod exp. ; C, Reddish prominence and axial growth of lettuce; & D, Sideways growth of summer lettuce.

Second study – Experimental results (Contd.)

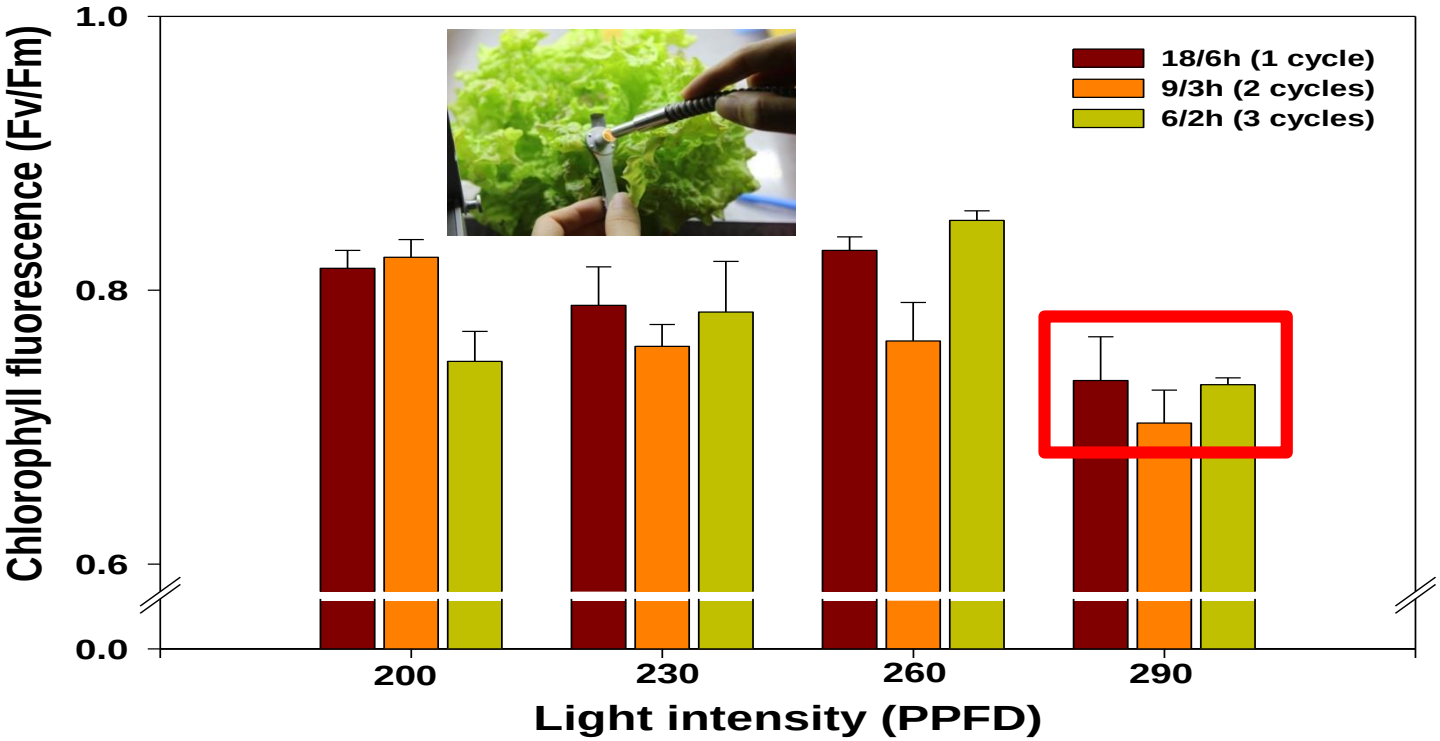


Fig. 2. Chlorophyll fluorescence as affected by light intensity & photoperiod of lettuce in a closed type plant production system.

- **Light intensity of 200~260 PPFD showed decreased stress intensity whereas at 290 PPFD more stress and tip-burn symptoms were observed**
- **Optimal production of economical and high quality was narrowed to the light intensity range of 230-260 PPFD**

Second study – Experimental results (Contd.)

Photo. 6. Effect of light intensity & photoperiod on growth & development of sowthistle in a closed-type plant production.

- **Light intensity of 230~260 PPFD produced excellent above-ground and below-ground growth in sowthistle**
- **At high light intensity of 290 PPFD tip-burn was observed**

Second study – Experimental results (Contd.)

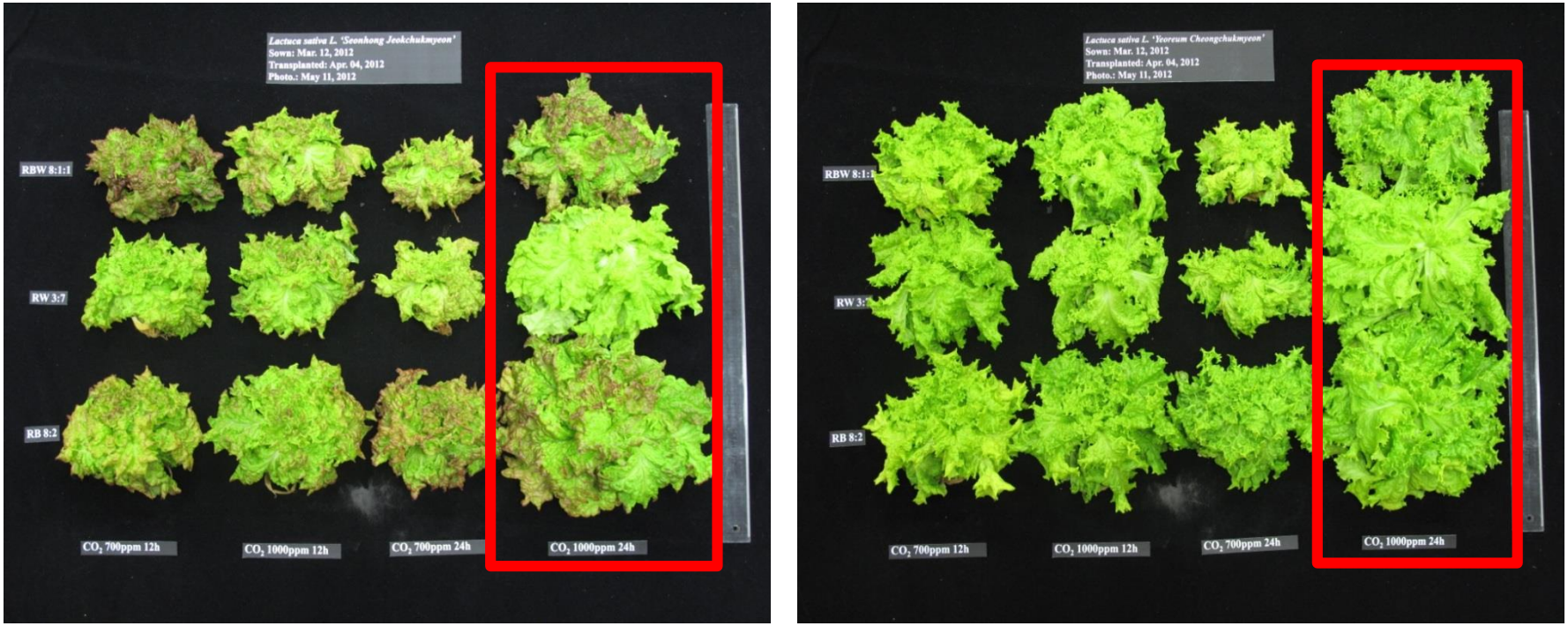


Photo. 7. Effect of light quality & concentration and supply duration of CO_2 supply on growth & development of lettuce grown in a closed-type plant production system. The light quality used were R:B:W=8:1:1, R:W=3:7 & R:B=8:2; & concentration and supply duration of CO_2 at 700 (12 h), 700 (24 h), 1,000 (12 h), and 1,000 (24 h) ppm.

Second study – Experimental results (Contd.)

Photo. 8. Effect of light quality & concentration and supply duration of CO_2 on growth & development of sowthistle grown in a closed-type plant production system. The light quality used were R:B:W=8:1:1, R:W=3:7 & R:B=8:2; & concentration and supply duration of CO_2 at 700 (12 h), 700 (24 h), 1,000 (12 h), and 1,000 (24 h) ppm.

Third study – Experimental results

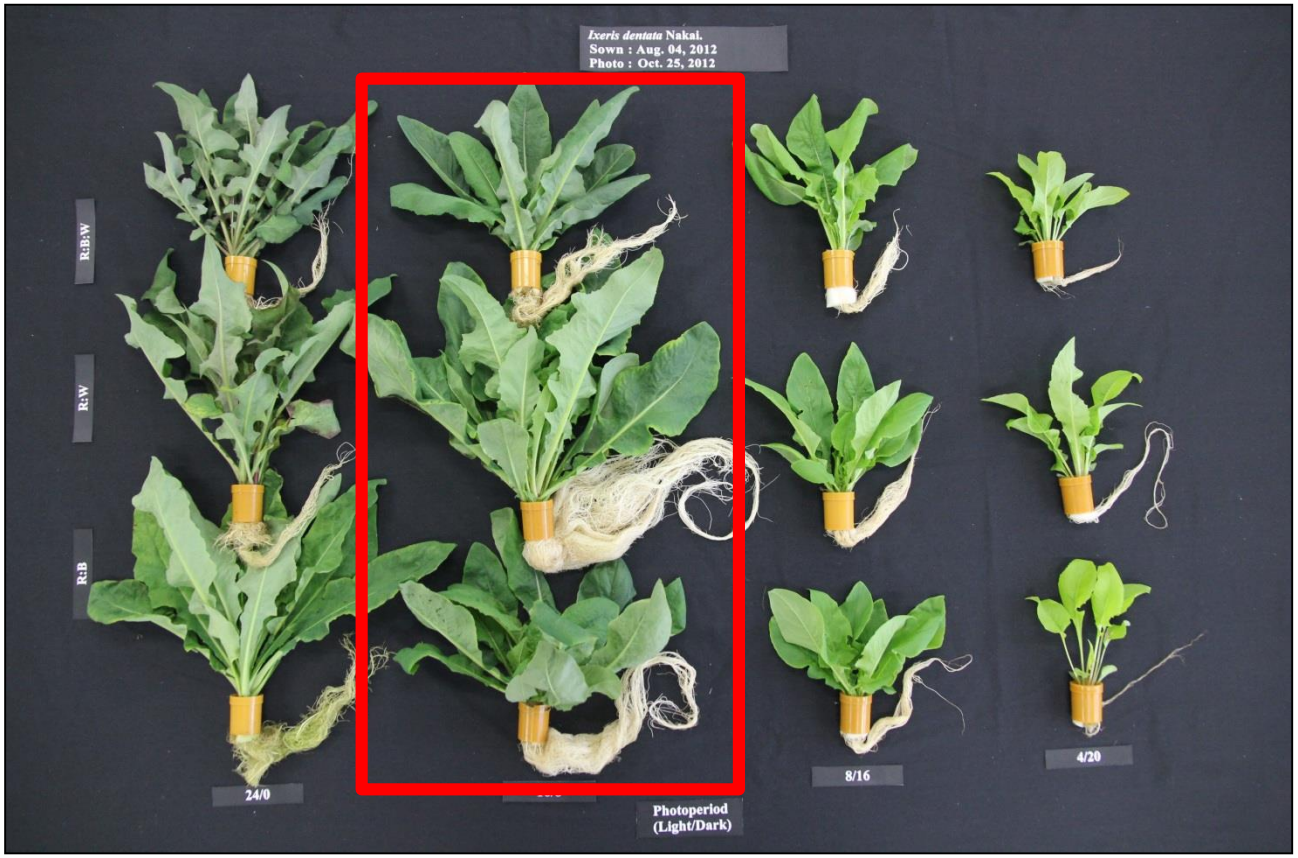


Photo. 9. Effects of light quality & photoperiod on the growth of sowthistle in a closed type plant production system. The light quality provided by the 3 LEDs (R:B:W=8:1:1, R:W=3:7, or R:B=8:2) (FC Poibe Co. Ltd., Korea) & photoperiods (Light/Dark) were 24/0, 16/8, 8/16 or 4/20.

Research objective

To evaluate different light qualities combined with the use of eco-friendly surface anodized growing gutters on the growth and development of leaf lettuce (*Lactuca sativa* L. 'Jeockchima') in a closed-type plant factory system.

- **Photographs showing growth of hydroponically grown lettuce in anodized gutters under three different lighting systems in a closed-type plant production system.**
- **It is visibly clear that lettuce plants grown under LED lighting showed better growth and less shrinkage when compared to fluorescent light.**

Research infrastructure

Research Facilities

Culture rooms with different light sources installed

Preparation area

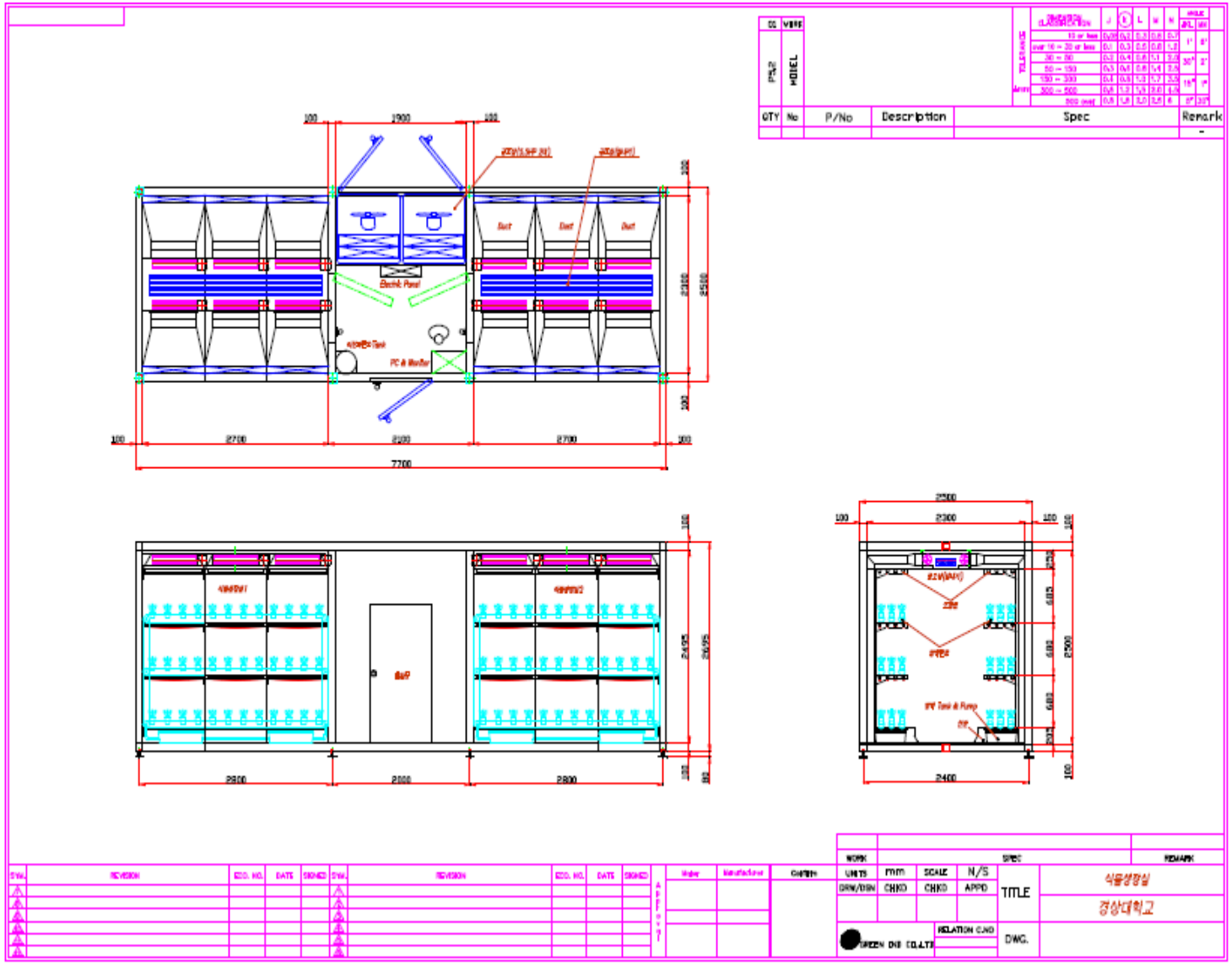
Plant factory

Greenhouse

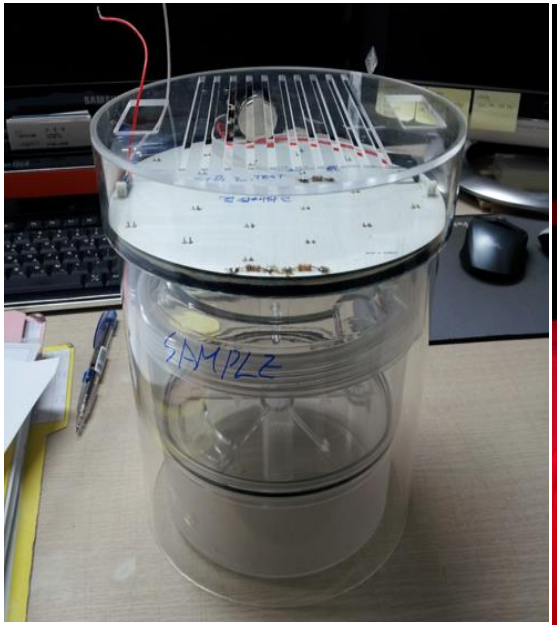
식물공장(Plant Factory)

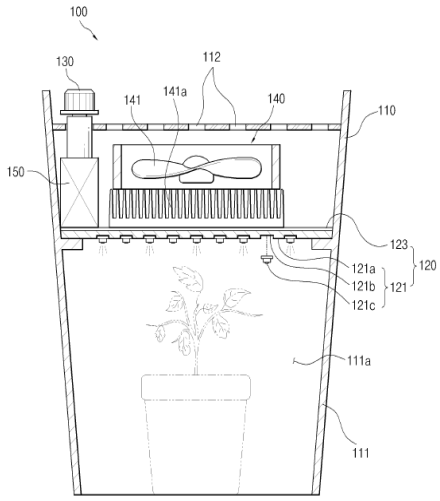
V-METER
A-METER
V-METER
A-METER
TEMP & HUMI CONTROLLER
TEMP & HUMI CONTROLLER

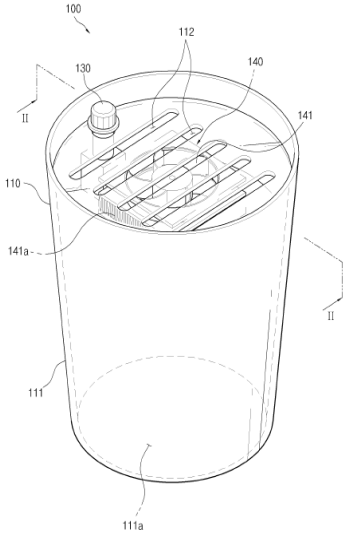
Plant factory – Schematic sketch



LED system designed for lab-scale experiments







Patent pending

Medicinal plants used so far…

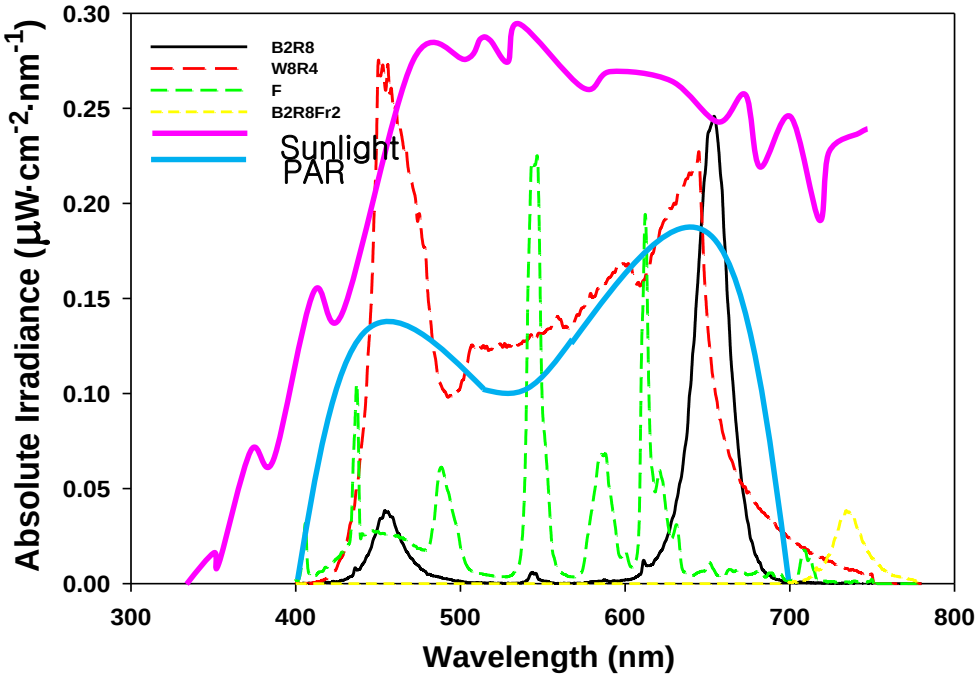
***Perilla frutescens* var. *acuta* Kudo**

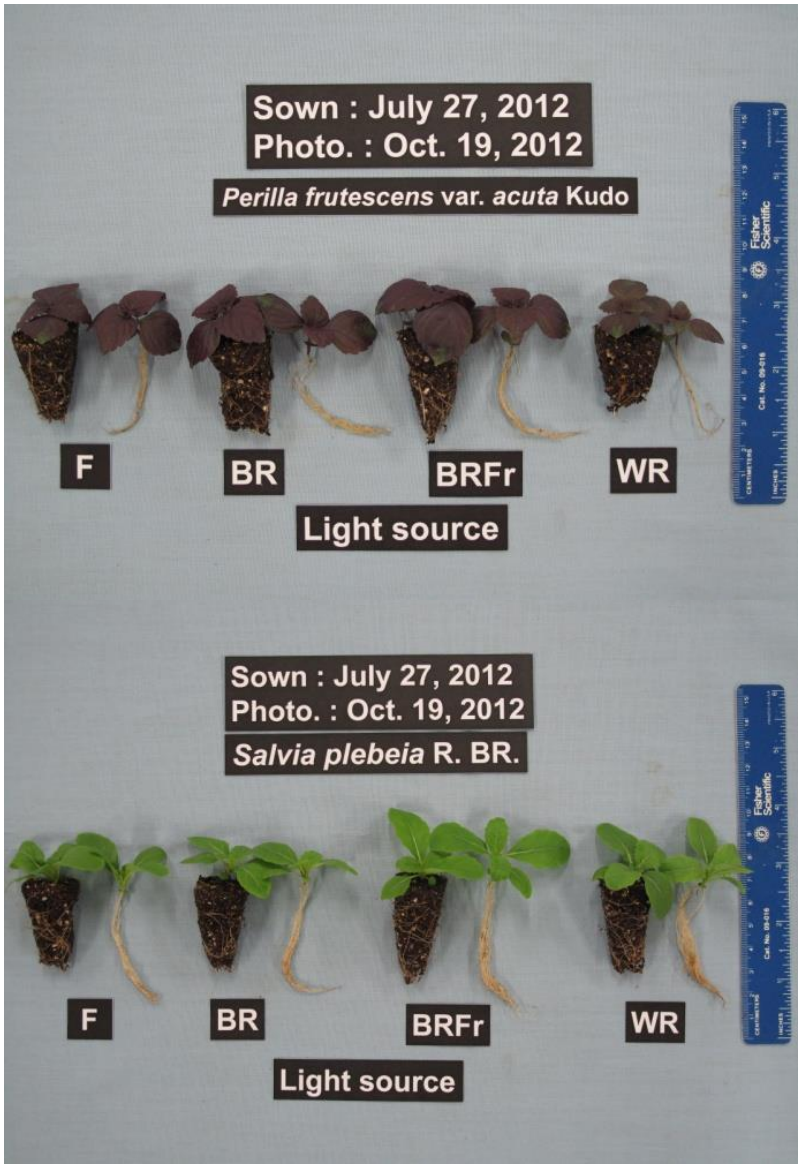
***Salvia plebeia* R. Br.**

***Angelica gigas* Nakai**

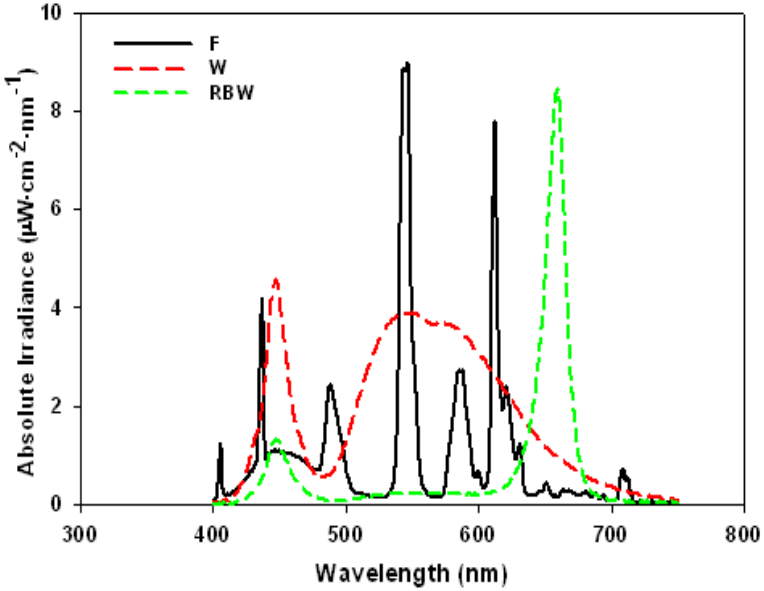
Ligularia fischeri

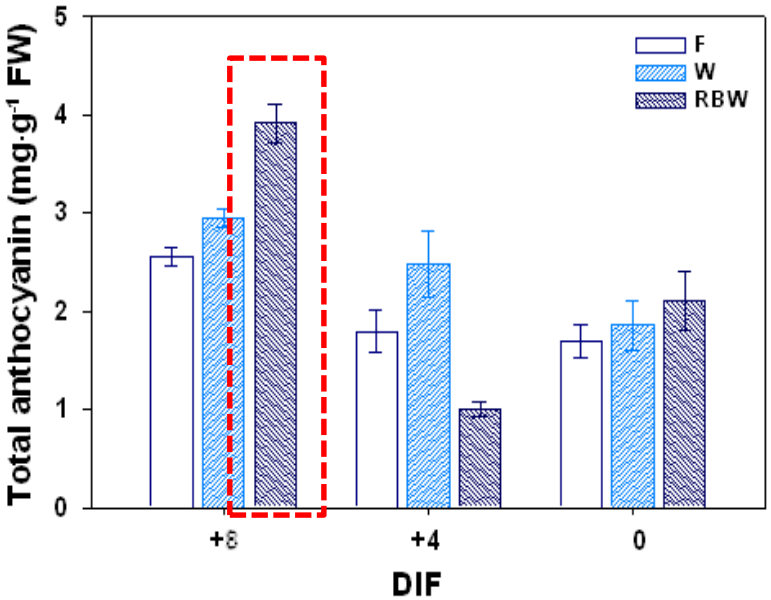
Effect of light quality on growth of *Perilla frutescens* var. *acuta* Kudo & *Salvia plebeia* R. BR.

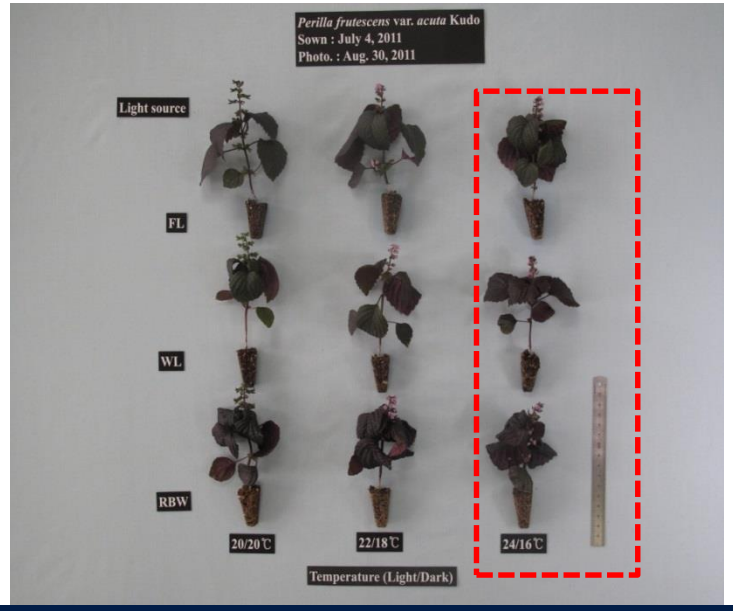


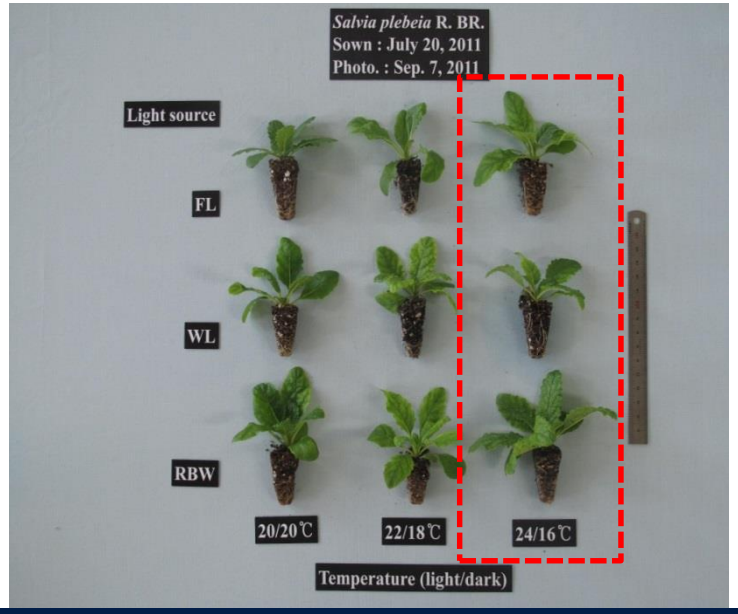


Medicinal plants - Influence of light quality

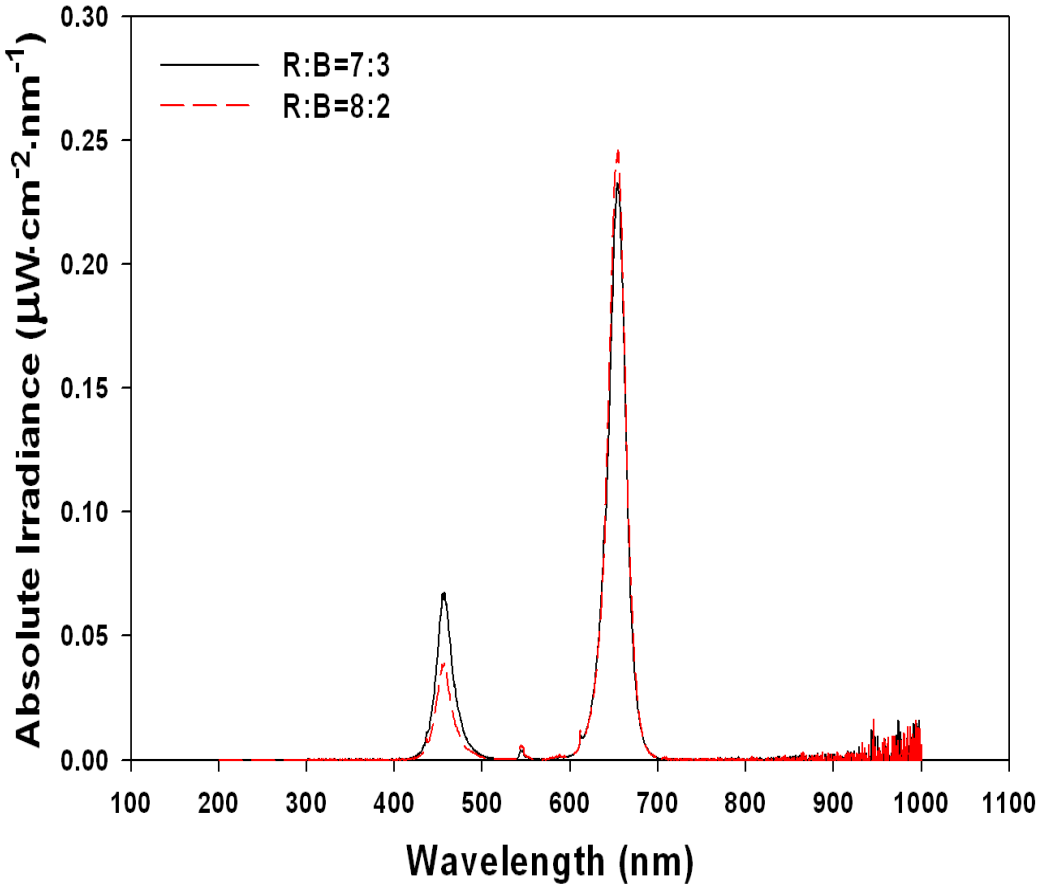


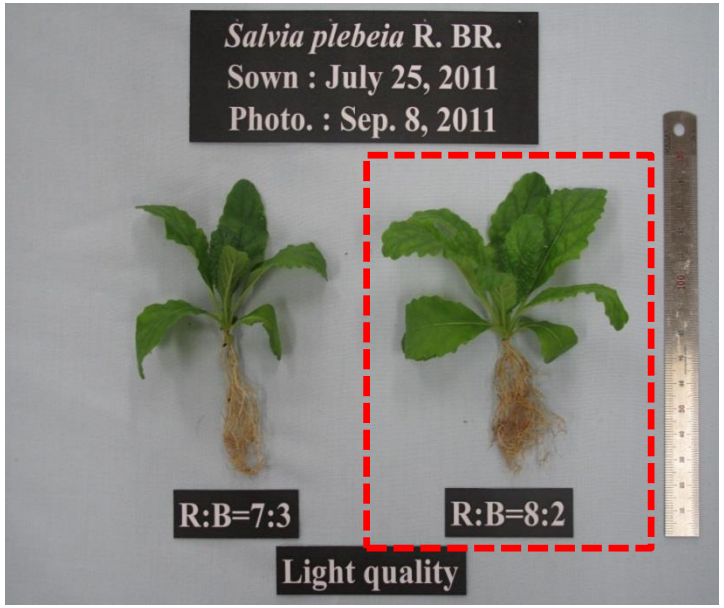


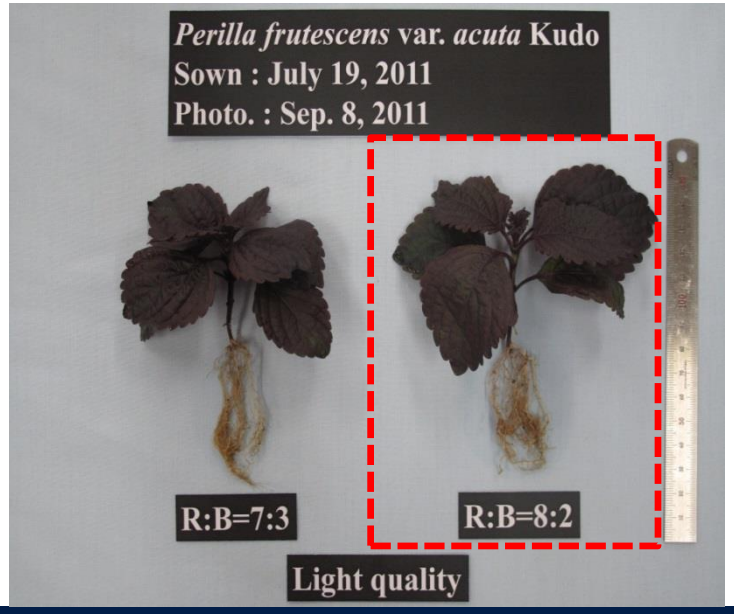




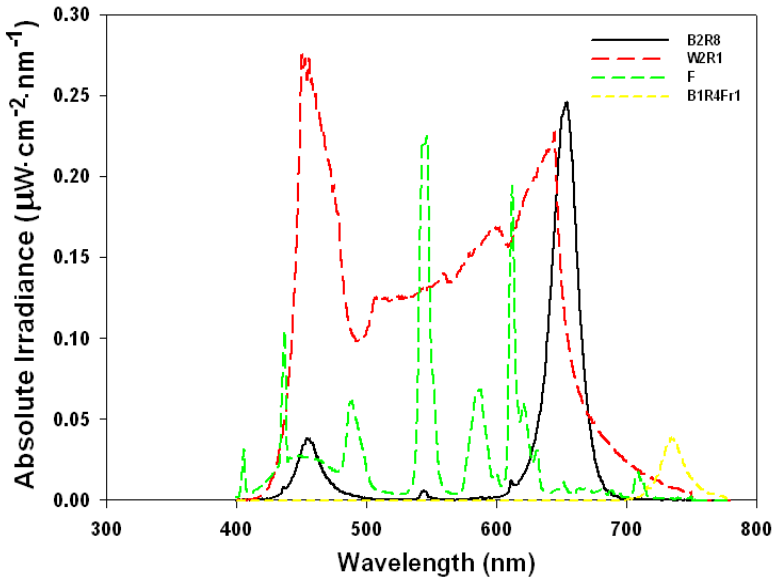
Medicinal plants - Influence of light quality

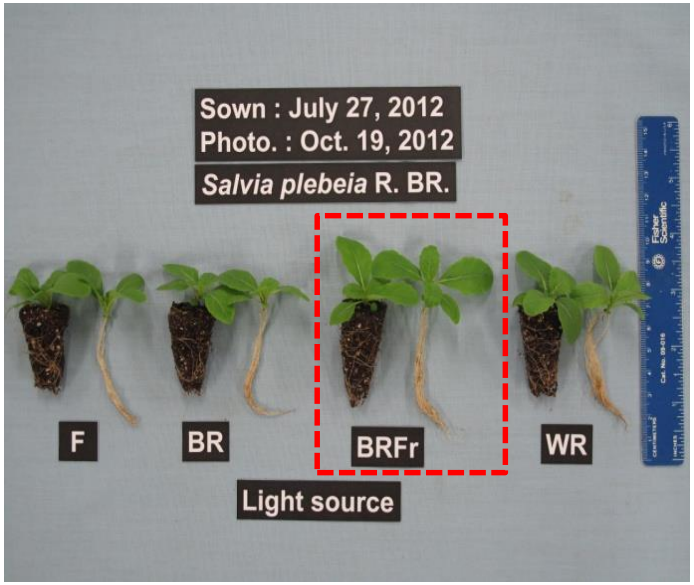


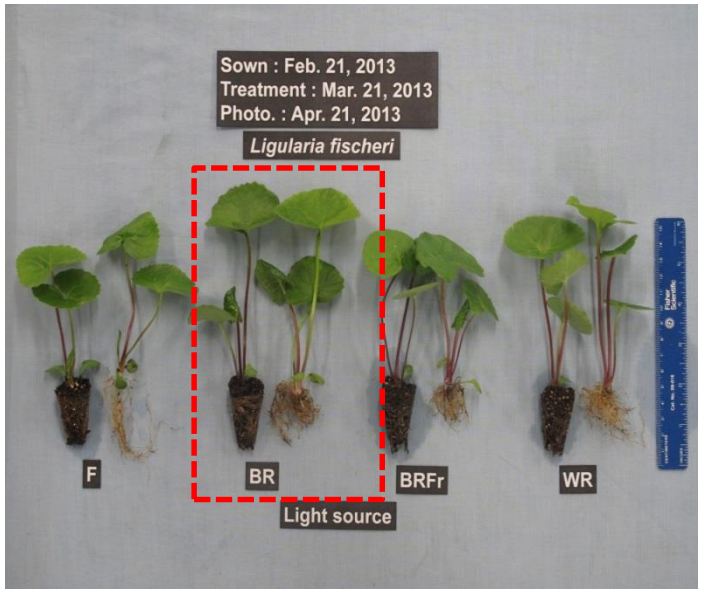


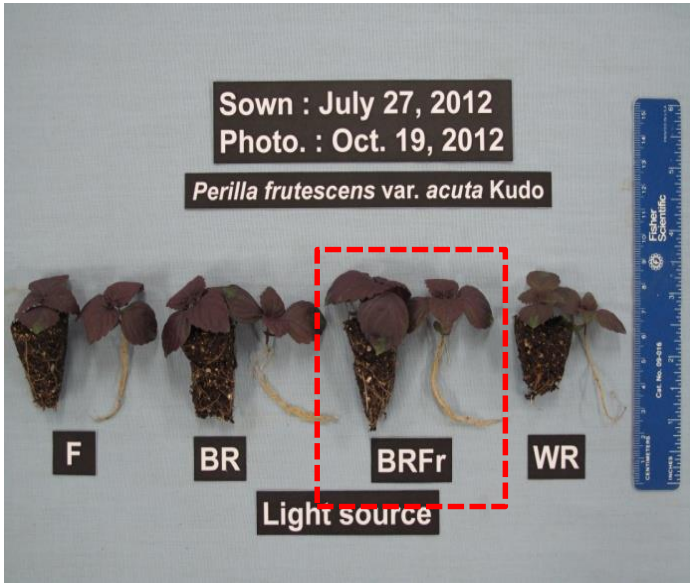


Medicinal plants - Influence of light quality

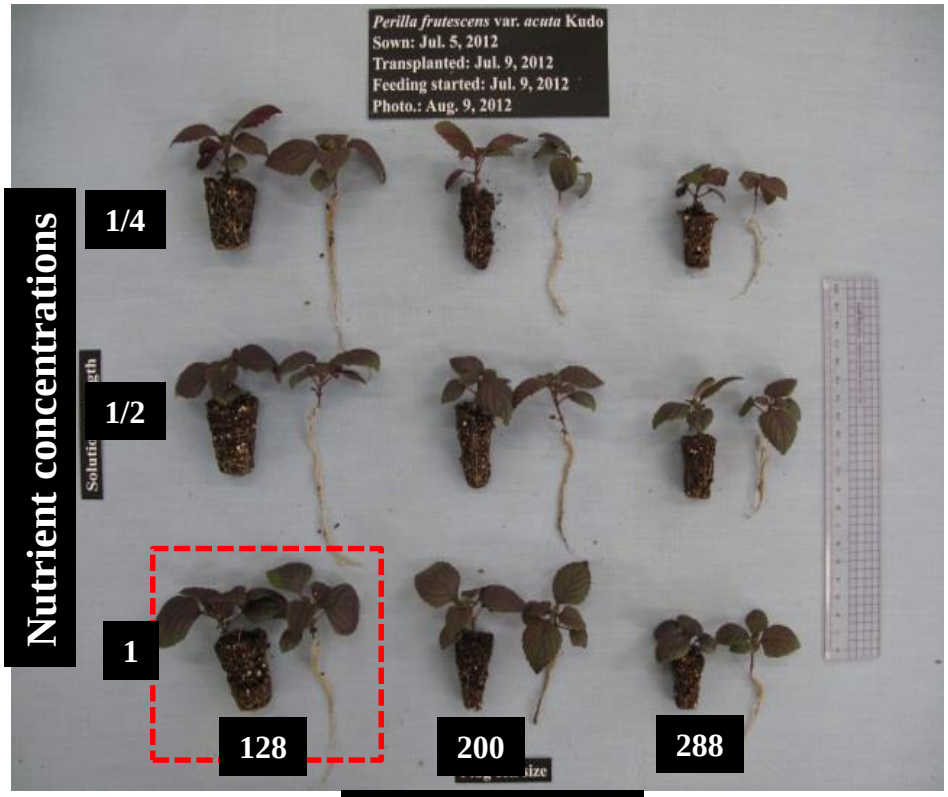




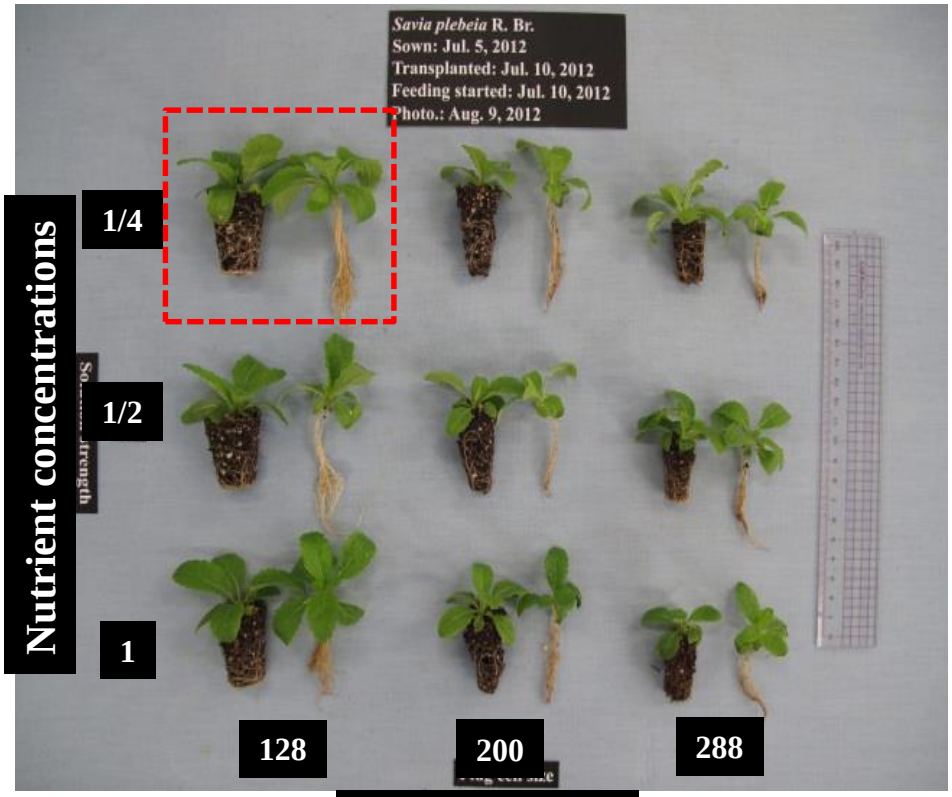




Medicinal plant factory

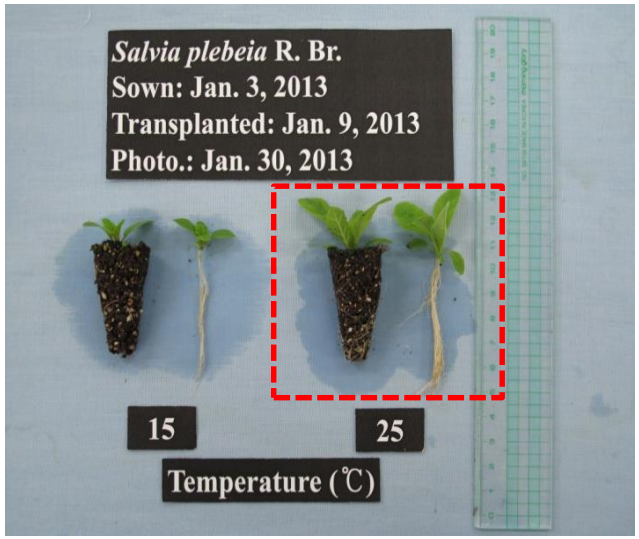


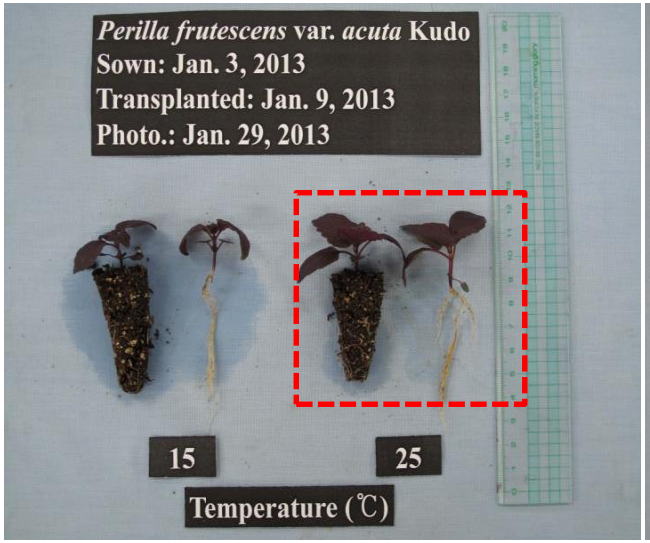
Plug cell size

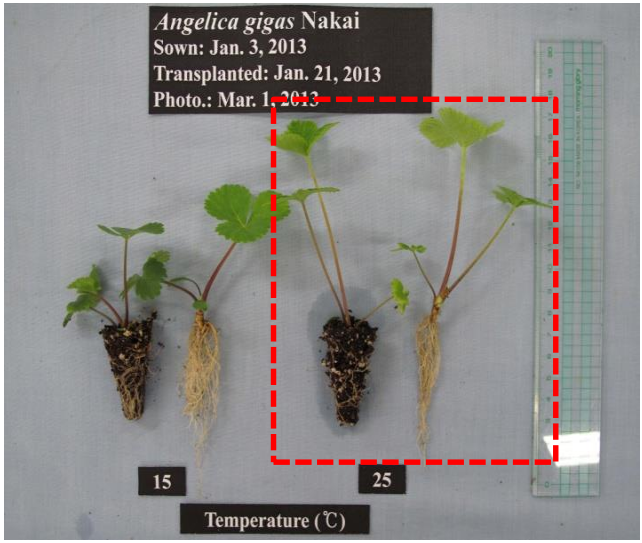


Plug cell size

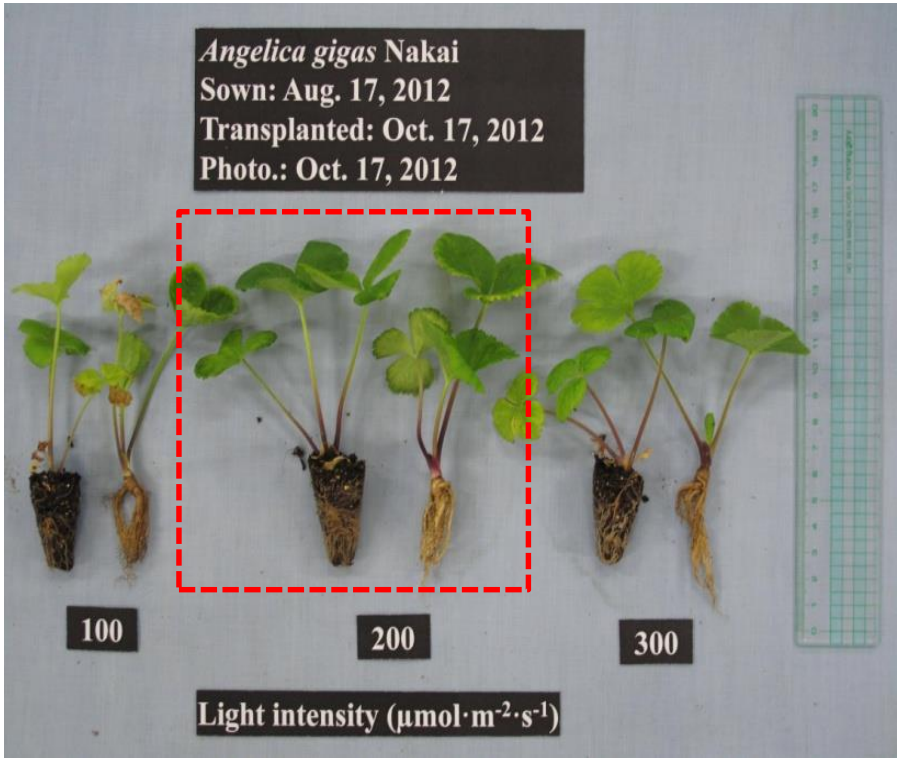
Medicinal plants – Effect of temperature

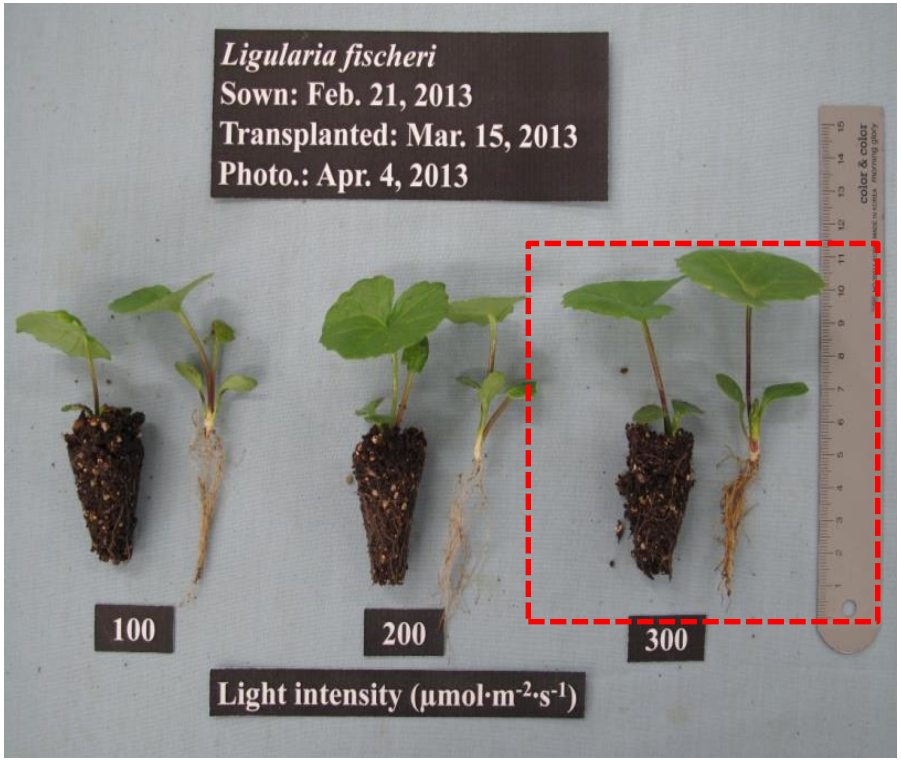




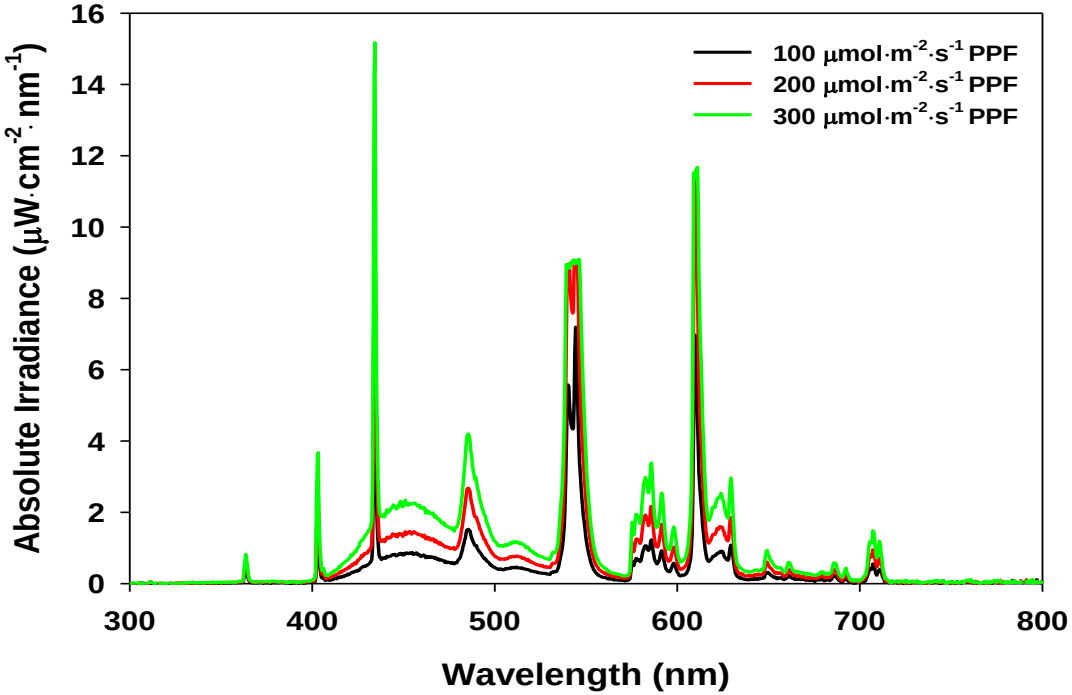


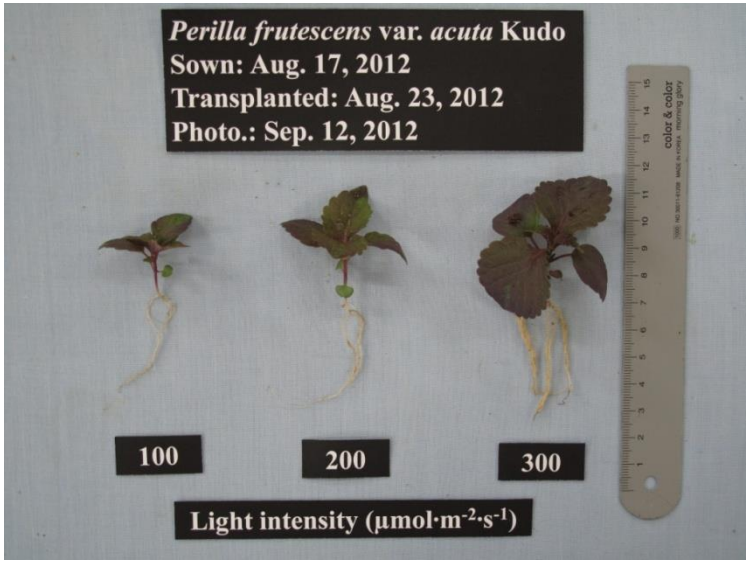
Medicinal plants – Effect of light intensity

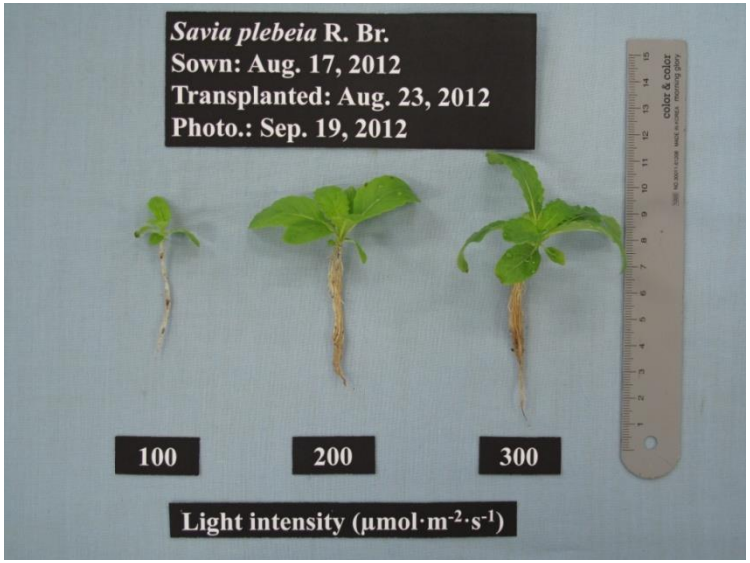




Effect of light intensity on growth of *Perilla frutescens* var. *acuta* Kudo & *Salvia plebeia* R. BR.

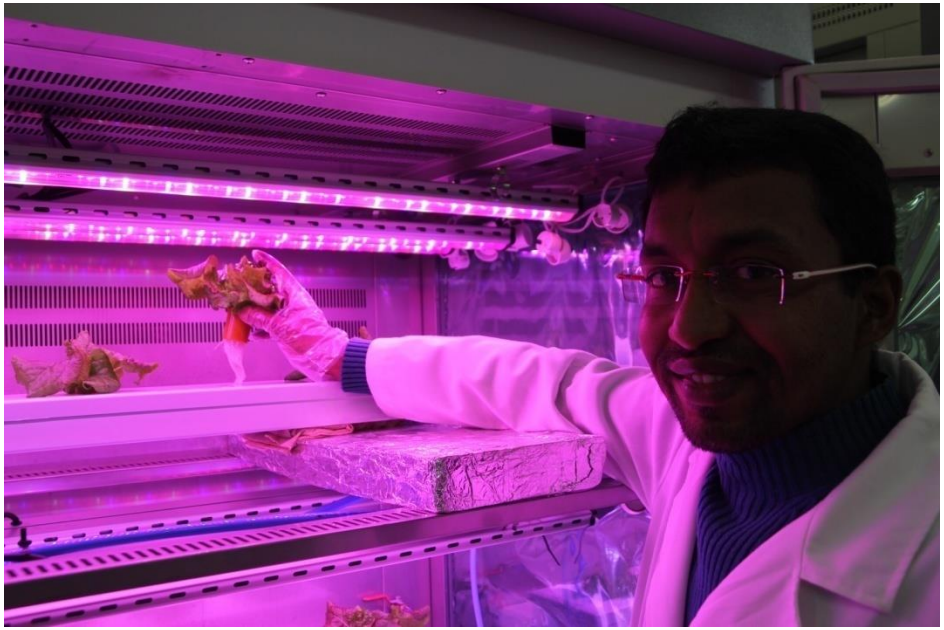






Graft healing chamber
(Jangseong Plug Co.)

- ~1 ha vegetable plug greenhouse
- Set points: 24℃ day/night, 100% RH (Circulation fans during the daytime)
- 1-2 days earlier healing + higher %
- Graft healing chamber: 332 m^2
  - Cost for installation including LED: $180,000
  - LED with a 2:1 red:blue ratio
- Holds 5,200 plug trays on 110 carts (80 carts more desirable for better air movement)
  - 5 or 6-tiered carts with LEDs on each tier



Thank you