SAMSUNG

Horticulture and LED Lighting

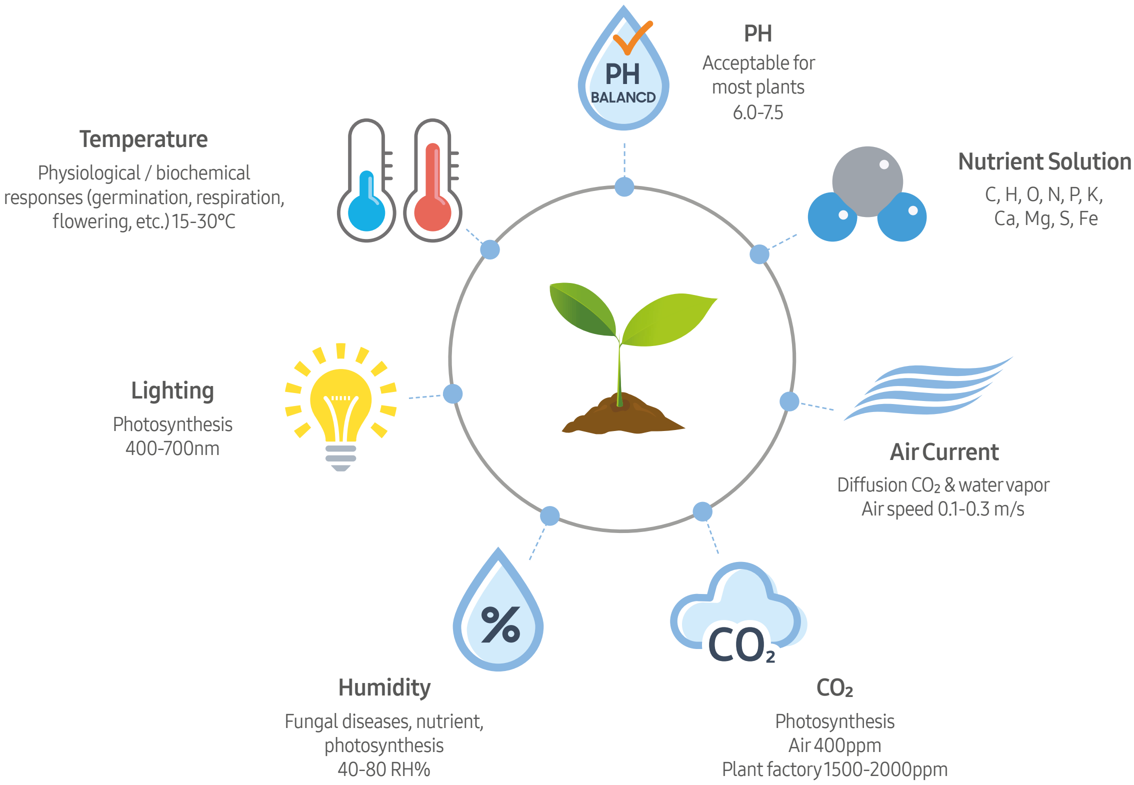
A Technical Brochure

Advanced Use of Light for Better Plant Growth

Jun. 2019

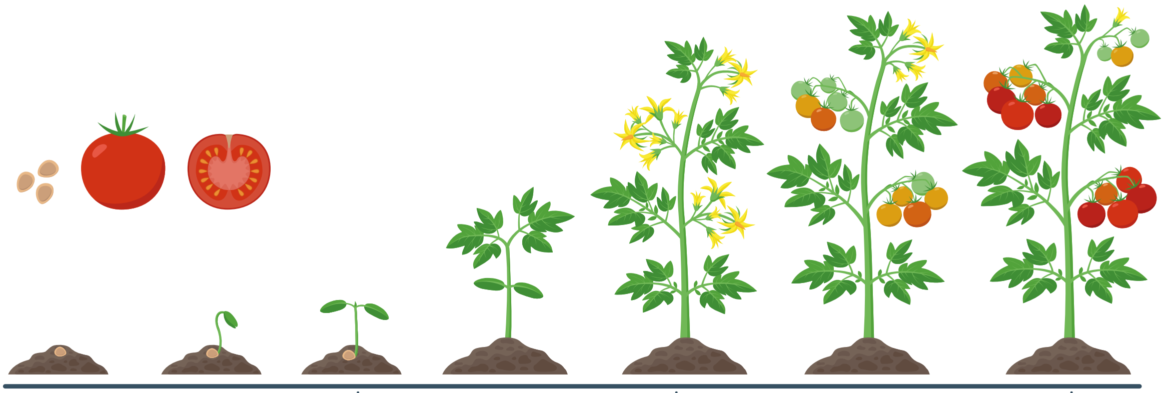
Important Factors for Plant Growth

The quality and quantity of light are two of the most important factors through which to enhance plant growth



The Influence of Lighting on Plant Growth

Plants require the appropriate light recipe for each growth cycle



Vegetative Growth

- Promotes vegetative growth
- Increases the total fresh weight

McCree and Keith J, Agricultural and Forest Meteorology (1972)

Photoperiod

- Controls the photoperiod of flowering
- Regulates the plant growth cycle

A. Yamada, Scientia Horticulture (2009)

Nutrition

- Produces secondary metabolities
- Valuable for health

G. Samuoliene, Food Chemistry (2012)

Leading Expert on Plant Factories

Dr. Toyoki Kozai

- Chiba University · Center for Environment, Health and Field Sciences

"White-based, full spectrum LEDs represent a great advancement in Horticulture Lighting and can improve a plant's photosynthesis, morphology, and disease resistance."

1972, Doctor of Philosophy, University of Tokyo
1977 – 2005, Professor, Chiba University (1977 – 1990, Associate Professor)
2005 - 2008, President, Chiba University
2008 - 2009, Professor, Center for Environment, Health and Field Sciences, Chiba University
2010 - Present, President of Japan Plant Factory Association

· Publications
200+ refereed papers, 50+ book chapters and 10+ books in English
· Major work
'Plant Factory', 2016 'LED Lighting for Urban Agriculture', 2018 'Smart Plant Factory'

"Kozai has recently been working on 'plant factory with artificial lighting (PFAL)' and has been leading the R&D of PFAL. His continuous quest in this field allowed him to dive deeper into this subject. He has been invited as a keynote speaker on the PFAL to more than 20 international symposia during 2015-2018."
-08. Jan. 2019 –PR.com

Leading Expert on Horticulture Lighting

Prof. C. Chun

- Seoul National University · Department of Plant Production Science

"Samsung's white-based horticulture LEDs which blend RGB colors offer a wide spectrum of wavelengths, making them more effective in indoor farming."

1994, Doctor of Philosophy, University of Tokyo
1994 - 1997, Purdue Univ. Researcher of NASA Specialized Center
1997 - 2000, Associate Professor, Chiba University
2001 – 2003, Associate Professor, Department of Plant Production Science, Chiba University
2003 – 2007, Associate Professor, Department of Plant Production Science, Seoul National University
2007 - Present, Professor, Department of Plant Production Science, Seoul National University

· Publications
95+ refereed papers, 10+ books in English & Korean
· International Society for Horticultural Science
· American Society for Horticultural Science
· Japanese Society for Horticultural Science

Leading Expert on Plant Factories

Dr. Toyoki Kozai

- Chiba University · Center for Environment, Health and Field Sciences

Q What trends are gaining traction in the Japanese horticulture market?
What are the important growth indicators?

A Vertical farming with advanced technologies such as the latest LED lighting and airconditioning, is essential to next-generation plant factories. Many companies are involoved in this new trend. Fresh weight is the most important index. Because LED provides efficient energy usage and easily adjustable wavelengths, increased and constant yields can be obtained throughout the year. Marketability, nutrition, and texture of the plants are also considered. Nutrition such as vitamin C can be controlled with preset light solutions and much research has been conducted on the effect of light on nutrition in leafy vegetables, strawberries and tomatoes.

Q What are the advantages of white-based full spectrum compared to narrow blue and red spectrum?

A White-based full spectrum containing green wavelength provides well-balanced plant growth compared to the blue and red narrow spectrum, so I think of green as very important wavelength to plant growth. Full spectrum could reduce lighting system costs for a simplification package and has advantages in aspects of photosynthesis, insect resistance, morphology and nutrition. Furthermore, because green light has higher penetration, sufficient light could reach the plant’s lower parts, resulting in effective photosynthesis.

Q Does Samsung Electronics envision an ultimate solution for the horticulture industry?

A I am very pleased that Samsung Electronics is one of the global companies most interested in horticulture lighting. If Samsung wants to be a global leader in the horticulture industry, a smart farming solution is essential. In smart farming, the key factor is providing the appropriate lighting solutions during each plant's growth cycle using vision recognition technology.

Samsung’s Smart Lighting Platform

Leading Expert on Horticulture Lighting

Prof. C. Chun

- Seoul National University · Department of Plant Production Science

Q What is the role of LED lighting in plant factories?

A LED lighting can not only control plant growth and photosynthesis, but also improve the taste and the mix of nutrients. Even with the same kind of vegetables, taste can be sweeter or more bitter, and the texture can be softer or stiffer depending on the LED lighting spectrum. LED lighting has advantages over conventional lighting because it generates less heat and spectrum that is easier to control.

Q What are the important functions obtainable for wavelengths in LED light sources?

A The wavelength of the 400-700 nm region (PAR) affects a plant's photosynthesis. The blue region increases the nutrient composition by defense mechanism, the green region increases the photosynthetic efficiency by penetration, and the red region directly influences the flowering and fruit period. Recently, it also has been reported that far-red regions have been used to achieve more efficient photochemistry and photosynthesis.

Q What is your opinion, as an expert, on "One Package" that Samsung Electronics will show soon?

A Compared with existing modules (white with expensive red packages), the total module cost can be significantly reduced and management costs can also be reduced in terms of inventory management. In addition, it is expected that growth uniformity can be obtained by increasing the uniformity of PPFD in the cultivation space through the use of a single package.

Samsung Horticulture LED

Influence of Wavelength on Plant Growth

An optimal strategy for using high-quality LED lighting in horticulture would be to select the best spectra for a specific crop or cultivar, one that offers improved quality in the most energy-efficient way. Red and blue lights fit with the absorption peak of chlorophylls involved in photosynthesis, as illustrated in Fig. 1 [1]. Red radiation is often considered the most efficient at driving photosynthesis based on the quantum yield. Blue light, however, is essential for both the vegetative and flowering stages of plant growth. Until now, these functions have made for a conventionally narrow horticulture spectrum by simply employing a combination of blue and red lights – an approach widely used in Europe.

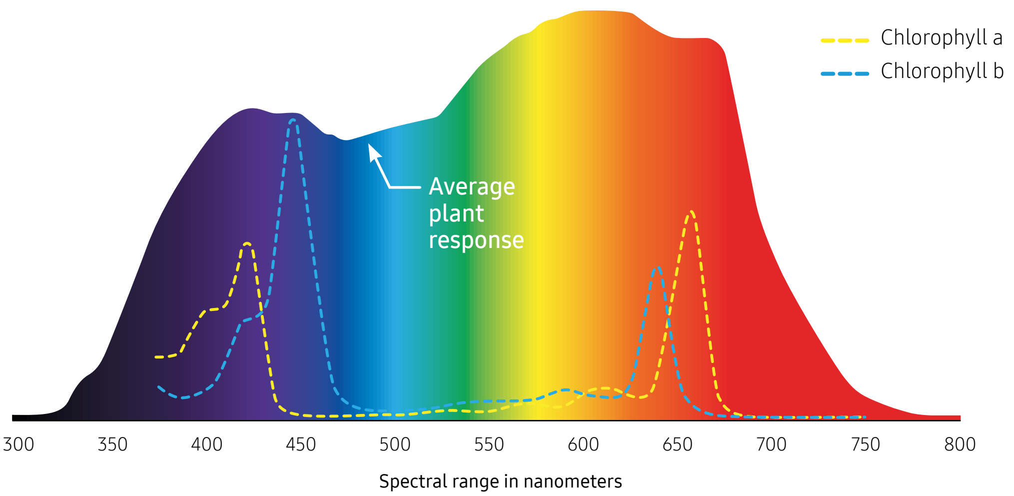


Figure 1. Chlorophyll absorption and photosynthetic response to absorbed photons at different wavelengths

Even though the dissolved chlorophyll (a and b) absorbs most of the photosynthetic benefits that were lost in the red and blue regions of the spectrum, and more weakly in the green area, we have found that red, then green, followed by blue light, is most effective in photosynthesis, based on the quantum yield for CO_2 fixation on leaves. This is referenced in the McCree curve as seen in Fig. 1 [2]. Green light can penetrate deeper than blue or red light in the plant canopy due to its high transmittance, allowing light to reach the lower branches and leaves of the plant [3, 4]. The effects of each wavelength on plant growth are demonstrated in Fig. 2.

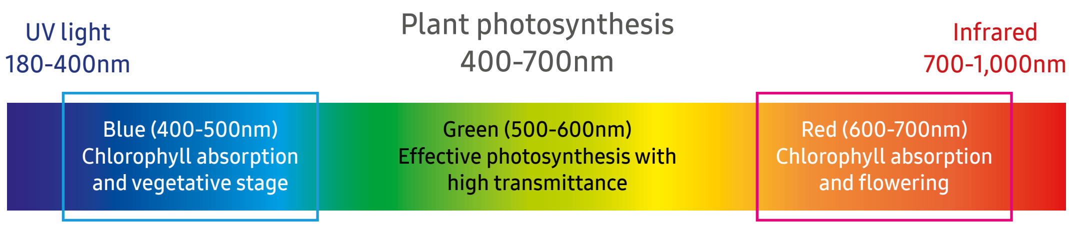


Figure 2. Wavelength effects on plant growth

[1] Renger G., "Concepts in Photobiology: Photosynthesis and Photomorphogenesis", New Delhi (1999).
[2] McCree and Keith J, "The action spectrum, absorptance and quantum yield of photosynthesis in crop plants", Agricultural and Forest Meteorology. (1972).
[3] Kozai N., "Plant factory with artificial light", Ohmsya Pub (2015).
[4] Jindong S., "Green Light Drives CO2 Fixation Deep within Leaves". Plant Cell Physiol. (1997).

Samsung Horticulture LEDs

Samsung has conducted spectral science trials for leafy greens and herbs with the purpose of improving plant growth and quality (Fig. 3). A series of experiments were conducted, upon the advice of noted horticulture lighting expert Professor Changhoo Chun from Seoul National University, Korea.

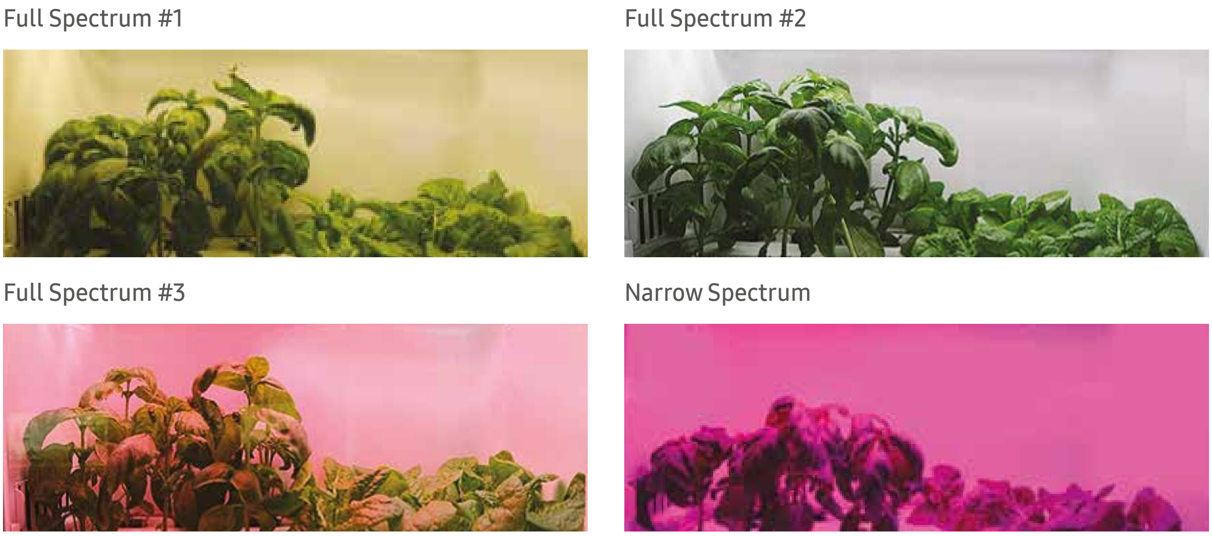


Figure 3. Growth chambers under 4 light conditions

The results show that Samsung broad spectra treatments outperformed the narrow ones, using comparative fresh weights (Fig. 4). This implies that the addition of light colors such as green and yellow, or 'full-spectrum' lights, produces better results than dual-colored (blue and red) lights. Our testing showed that green light can not only reach the bottom layer of leaves and branches due to its high transmittance, but can also contribute to signaling information that reverses the defense mechanism of UV/blue-light.

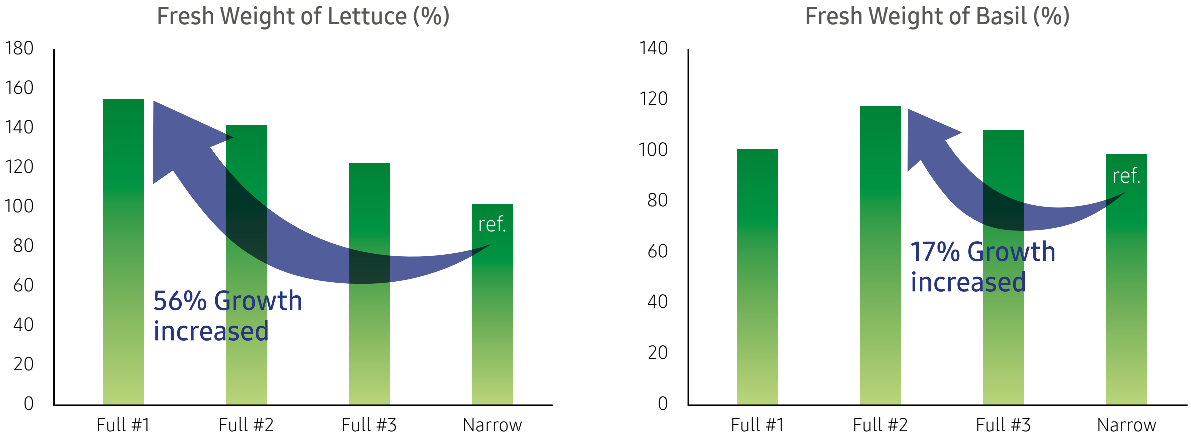
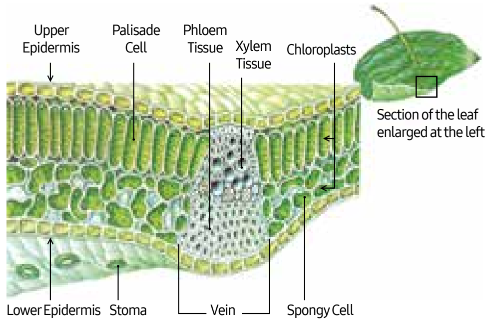
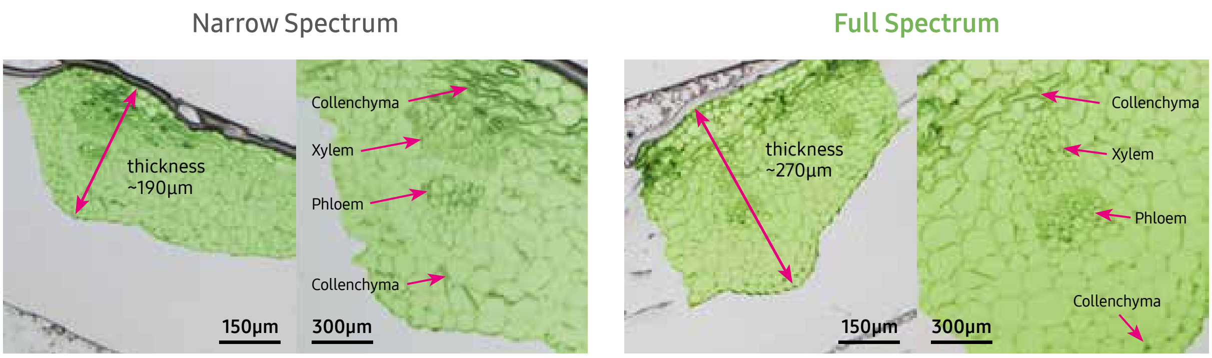


Figure 4. Performance of narrow and full LED spectrum

Healthier Growth Under Full Spectrum

· Cross-sections of leaves under narrow spectrum vs. full spectrum were compared
· Thicker leaves and other well-formed structures such as xylem and phloem were obtained from the use of full spectrum
· Full spectrum is not only cost-effective, but also produces better yields

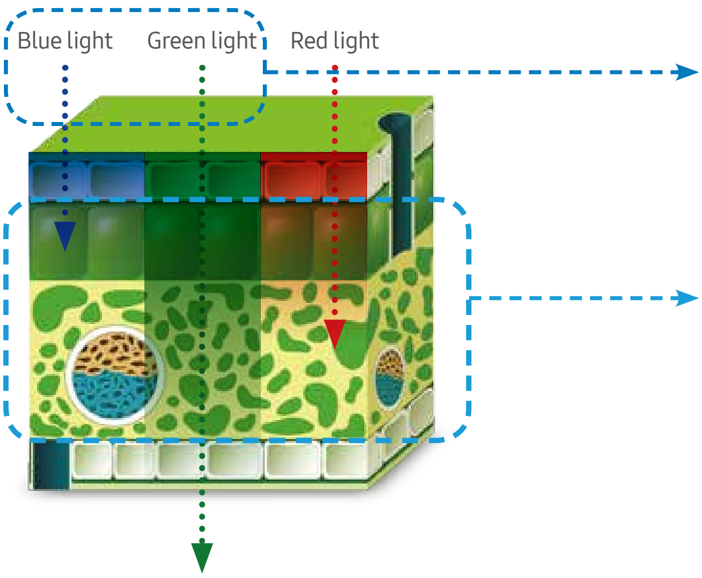




Acknowledgement: Prof. Chun at Seoul National University

Green Light's Effects on Plant Growth

Green light is helpful for balanced plant growth by improving many aspects of the growth cycle



Signaling

· Contributes to signaling information
· Reverse defense mechanism

1. Smith, J Exp Bot. (2017)

Photosynthesis

· Involved in photosynthesis
· Improved growth & morphology

1. McCree, Agricultural and Forest Meteorology (1972)
2. Terashima, HortScience (2004)

Penetration

· Reaches the lower branches and leaves of the plant
· Highly efficient photosynthesis for increasing overall leaf chlorophyll levels

1. Kozai, Ohmsya Pub P227 (2015)
2. Jindong, Plant Cell Physiol. (1998)

Signaling Effects and Supplementary Lighting for Strawberries

Spectral band quality also affects the photoperiod in various plant cultivations. Particularly, red and far-red lights play an important role in improving day extension, while flowering time is impacted by phytochrome regulation. [1]. Phytochrome has two different chemical structures (P_r, P_{fr}) that are inter-convertible. They absorb red light (660 nm) and far-red light (730 nm), respectively (Fig. 5). When P_r absorbs red light, it is converted to P_{fr}, a biologically active form of phytochrome.

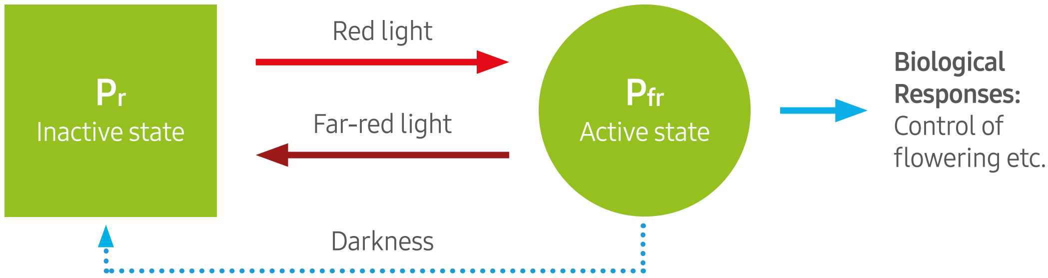


Figure 5. Schematic representation of phytochrome with two inter-convertible forms (P_r, P_{fr})

Supplementary lighting for strawberry cultivation is playing an important role in plant growth as demonstrated in Fig. 6. Strawberries are short-day (SD) cultivars, and their floral induction takes place in early autumn. As the saturated PPFD (photosynthetic photon flux density) is reportedly 800-1,200µmol/m²/s, using supplementary lighting can provide enough PPFD, resulting in significant additional vegetative growth. In northern Asian countries, supplemental lighting is applied mainly to prevent the plants from entering dormancy. Dormancy can stop growth throughout an entire winter, under natural conditions. Yet, by applying night breaking using supplementary lighting, strawberries can maintain healthy vegetative growth resulting in a more robust plant architecture. Lastly, for an optimized growth system using the white-based full spectrum of LED, the required time for one billion transplants can be reduced from 6 to 2 years (36 m² of cultivation area) [2].

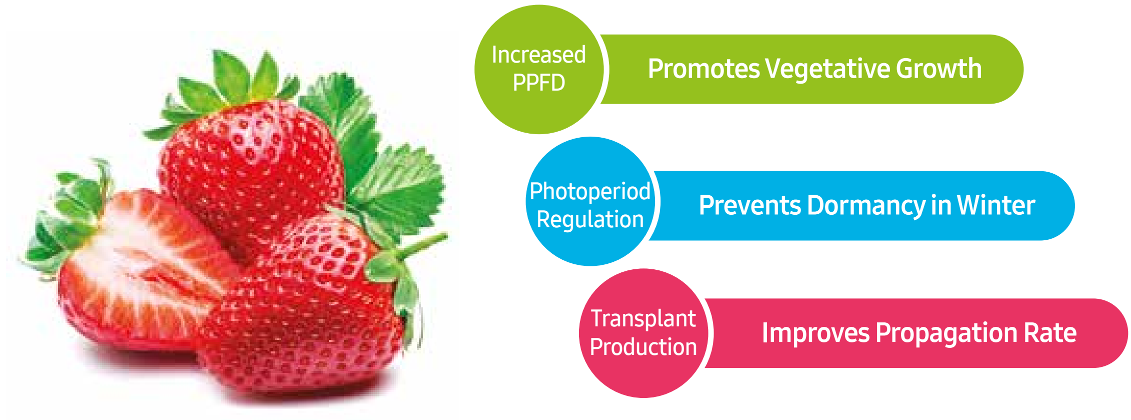


Figure 6. Effects of artificial lighting on strawberry production

[1] K. Halliday, "Phytochrome B and at least one other phytochrome mediate the accelerated flowering response of Arabidopsis thaliana L. to low red/far-red ratio." Plant Physiol. (1994).
[2] H. Lee, "Application of white LEDs to promote growth and propagation rates of strawberry transplants," Master Thesis, Seoul National University (2019).

Plant Nutritional Values for People

Various horticultural and medicinal plants contribute to human health. Plants have a variety of photoreceptors, so nutrients are mainly affected by cryptochrome that is stimulated by the UV-A/blue region of the spectrum and activates specific defense reactions (Fig.7). When a defense reaction is activated, plants consume energy in such a way as to produce secondary metabolites, such as vitamin C, anthocyanins and phenolic compounds that are valuable for human consumption.

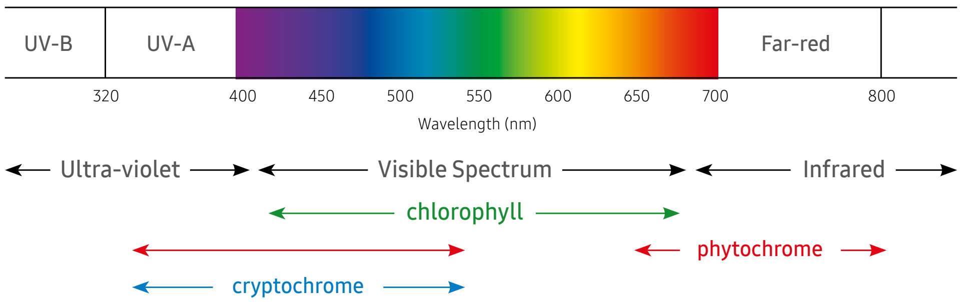


Figure 7. Visible wavelength with various photoreceptors

By applying optimized horticultural practices and environmental control, plant farmers can obtain enriched antioxidants from fruits and vegetables. The positive response of phytochemical formation with both blue and green lights is demonstrated in various leafy green vegetables [1-3]. As green light is efficiently transmitted through a plant's tissues, it may also trigger desirable reactions when not directly exposed to light stimuli, such as the metabolism of antioxidants. Also, the blue light increased the flavonoid content of tomatoes [4] and anthocyanin content of strawberries, even after harvest [5].

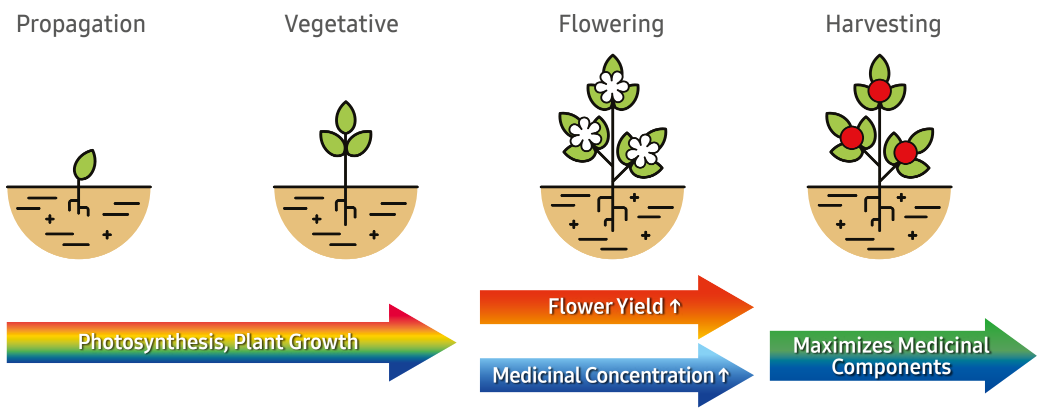


Figure 8. The role and condition of light at each plant growth stage

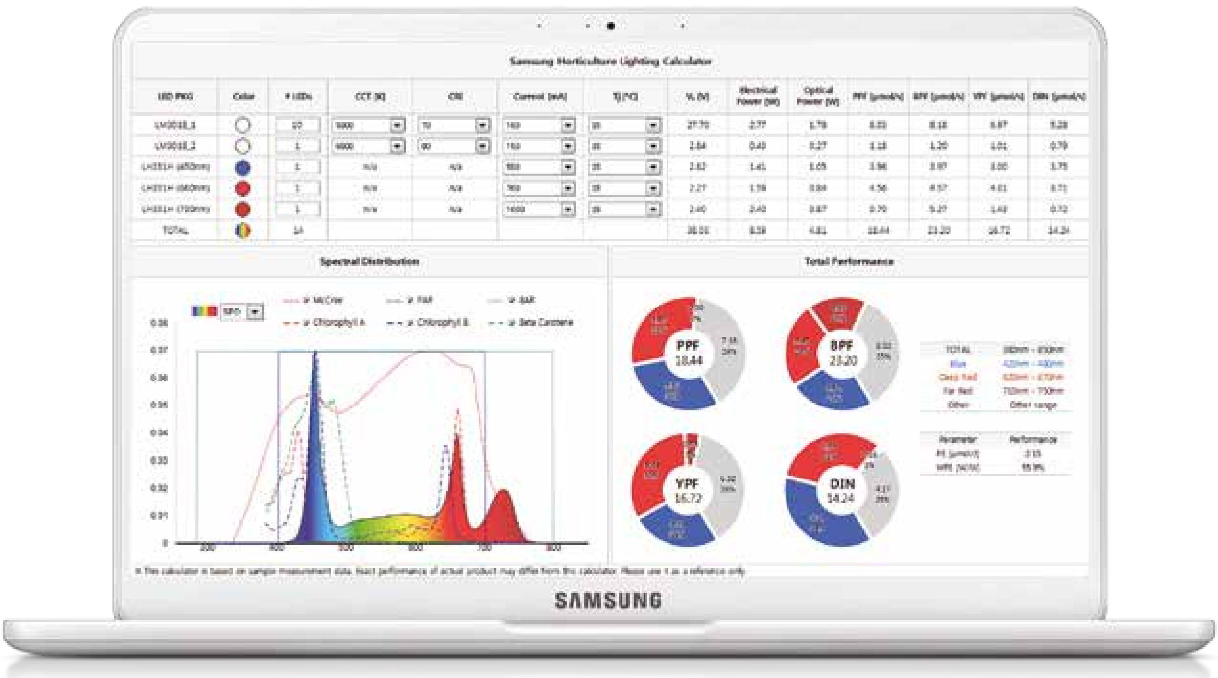
Plant cultivators can get medicinal components from specific floral tissues of plants. In terms of the maximum value of the medicinal component, a high yield of flowers can be obtained by using sufficient red light, and a high concentration of the medicinal component in the flowering state can be obtained by increasing the blue/UV light (Fig.8). Furthermore, the effect of enriched-green light reportedly makes specific chemicals that combine with medicinal components to maximize medicinal effects [6].

[1] K. Kim, "The Effect of Blue-light-emitting Diodes on Antioxidant Properties and Resistance to Botrytis cinerea in Tomato Plant", J Plant Pathol Microb (2013).
[2] M. Lefsrud, "Irradiance from distinct wavelength light-emitting diodes affect secondary metabolites in kale", HortScience (2008).
[3] J. Holopainen, "Forum New Light for Phytochemicals", Trends in Biotechnology (2018).
[4] T. Ouzounis, "Blue and red LED lighting effects on plant biomass, stomatal conductance, and metabolite ontent in nine tomato genotypes", Acta Horticulturae (2016).
[5] F. Xu, "Blue Light Irradiation Affects Anthocyanin Content and Enzyme Activities Involved in Postharvest Strawberry Fruit", J Agric Food Chem (2014).
[6] D. Hawley, T., "Improving Cannabis Bud Quality and Yield with Subcanopy Lighting", HORTSCIENCE (2018).

Fast, Beneficial & Reliable Choices for Horticulture Lighting with Samsung

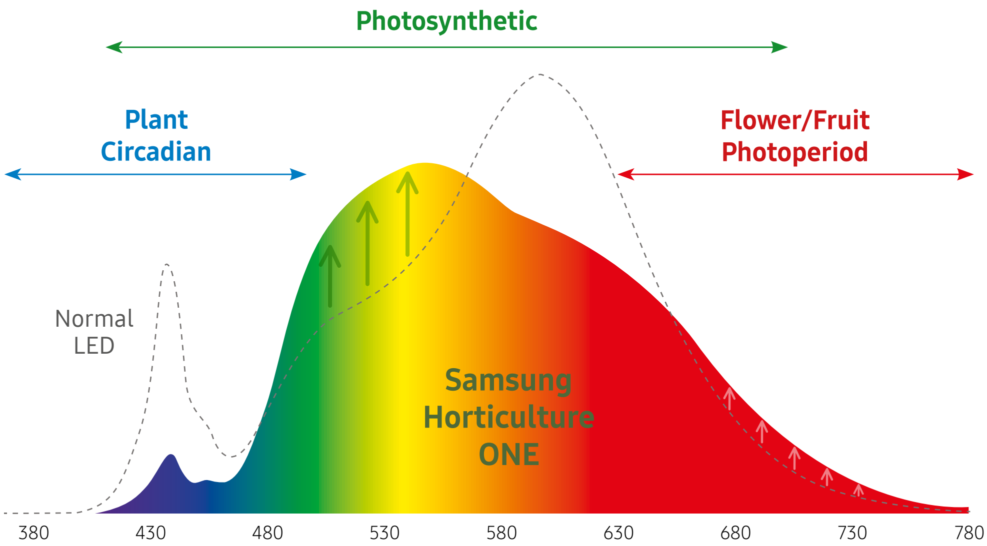
· Provides widest range of LEDs from LED packages to modules, mid-power to high power, and white to monochromic color
· Delivers industry-leading performance (3.1 μmol/J) and excellent reliability for horticulture applications in harsh environments
· Based on systematic research and repeated growth testing

Samsung Provides a Spectrum Simulation Tool to Support Customer Design



Samsung Horticulture_LM301H ONE

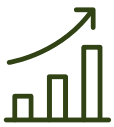
Samsung provides a single package solution with white spectrum that is better for plant growth



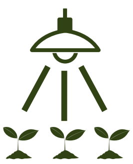
Samsung Horticulture_LM301H ONE

This growth-optimizing and cultivation-enhancing solution will be released in 2019.

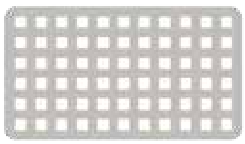
LM301H_ONE



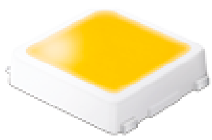
Improves Growth
- High speed of growth
- Better plant shape



Better Uniformity
- Improved uniformity of PPFD
- Uniform growth distribution



Convenient Process
- Low stock keeping unit (SKU)
- Simplified process



Mid Power LED (White)

LM301H

· 0.2W, 3V mid-power LED
· World's best efficacy
· Anti-sulfurization (with flip-chip technology)

@65mA, 25°C, 5000K, CRI80

Rank	Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
SL	White	0.56	3.10	3.0 × 3.0

LM561H

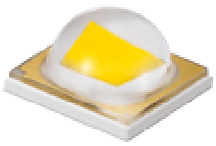
· 0.2W, 3V mid-power LED
· Balanced performance/cost
· Anti-sulfurization (with protection coating)

@65mA, 25°C, 5000K, CRI80

Rank	Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
SL	White	0.51	2.84	5.6 × 3.0

High Power LED (White)

LH351H-B

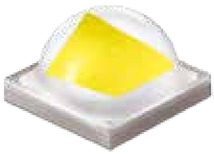


· 1.0W, 3V high power LED
· Viewing angle : 120°
· Thermal resistance : 4.0K/W

@350mA, 25°C, 5000K, CRI70

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
White	2.48	2.51	3.5 × 3.5

LH351H-C

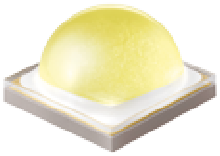


· 2.0W, 3V high power LED
· Viewing angle : 130°
· Thermal resistance : 3.0K/W

@350mA, 25°C, 5000K, CRI70

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
White	2.56	2.60	3.5 × 3.5

LH351H-D



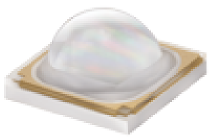
· 3.0W, 3V high power LED
· Viewing angle : 130°
· Thermal resistance : 2.2K/W

@350mA, 25°C, 5000K, CRI70

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
White	2.58	2.69	3.5 × 3.5

High Power LED (Color)

LH351H Blue
(450nm)

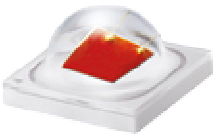


· 1.0W, 3V high power LED
· Viewing angle : 130°
· Thermal resistance : 4.0K/W

@350mA, 25°C

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
Blue	2.80	2.80	3.5 × 3.5

LH351H Red
(630nm)

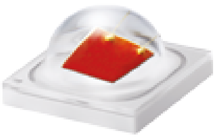


· 0.7W, 2V high power LED
· Viewing angle: 120°
· Thermal resistance: 4.0K/W

@350mA, 25°C

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
Red	1.57	2.14	3.5 × 3.5

LH351H Deep Red
(660nm)

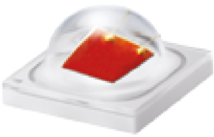


· 0.7W, 2V high power LED
· Viewing angle : 120°
· Thermal resistance : 2.5K/W

@350mA, 25°C

Color	PPF (μmol/s)	PPF/W (μmol/J)	Footprint (mm²)
Deep Red	2.32	3.12	3.5 × 3.5

LH351H Far Red
(730nm)



· 0.7W, 1.9V high power LED
· Viewing angle : 120°
· Thermal resistance : 3.9K/W

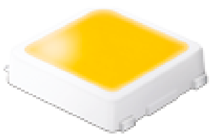
@350mA, 25°C

Color	* BPF (μmol/s)	* BPF/W (μmol/J)	Footprint (mm²)
Far Red	1.96	2.91	3.5 × 3.5

* Biologically-active Photon Flux

Specilized LED

LM301H_ONE



· 0.2W, 3V mid-power LED
· Experimentally designed white spectrum
· Easy SMT and SKU management
· More uniform light distribution
· Specification is to be determined

Horticulture Linear Module

Item	LED type	CCT	Flux	Efficacy	PPF	PPF/W	If	Vf	Watt	Tp
Unit	-	K	lm	lm/W	μmol/s	μmol/J	mA	V	W	°C
1ft	White + Red	5,390	4,110	159	70.9	2.74	1,200	21.5	25.8	25
2ft		5,390	8,220	159	141.8	2.74	1,200	43.1	51.7	25

※ Conformal coating is optional

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