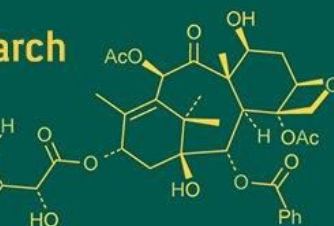


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A novel design strategy for developing grow-lights using CFLs and LEDs

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Abstract

Controlled environment agriculture (CEA) requires precise regulation of light, temperature, and humidity to ensure efficiency of plant growth based research. Conventional growth chambers generally do not possess spectral flexibility, non-uniform light distribution, and high electricity consumption. This study presents the design, development, and performance evaluation of a novel modular LED-based dimmer-augmented plant growth chamber intended for research-scale plant growth applications. The proposed system integrates a spectrally tunable LED lighting unit. The lighting system consists of a combination of red, blue, and white LEDs arranged to achieve uniform photosynthetic photon flux density (PPFD) across the plant canopy. Results indicated a PPFD uniformity coefficient of 0.69. Preliminary plant growth trial for *Chrysanthemum morifolium* cv. Zembra demonstrated healthy growth in terms of plant height and number of leaves and early flowering behaviour. The developed growth chamber offers a cost-effective method for plant research based applications and can be further customized based on hue-based modifications.

Keywords: LED lighting, growth chamber, controlled environment agriculture, spectral control, photochemistry

1. Introduction

Controlled environment growth chambers are essential tools in plant science research, allowing precise manipulation of abiotic factors such as light, temperature, humidity, and carbon dioxide concentration. These systems enable growth of plants under artificial environment and facilitate studies on plant physiology, stress responses, and crop improvement mechanisms.

Light is an important factor which influences various plant growth and developmental reactions. Traditional growth chambers generally have fluorescent or high-pressure sodium lamps as artificial light sources. The scope of spectral control is quite limited and the energy consumption is also on a higher level. The rapid advancement of light-emitting diode (LED) technology has enabled the development of growth chambers with energy-efficient lighting systems having a customizable spectral outputs tailored to plant photosynthetic requirements.

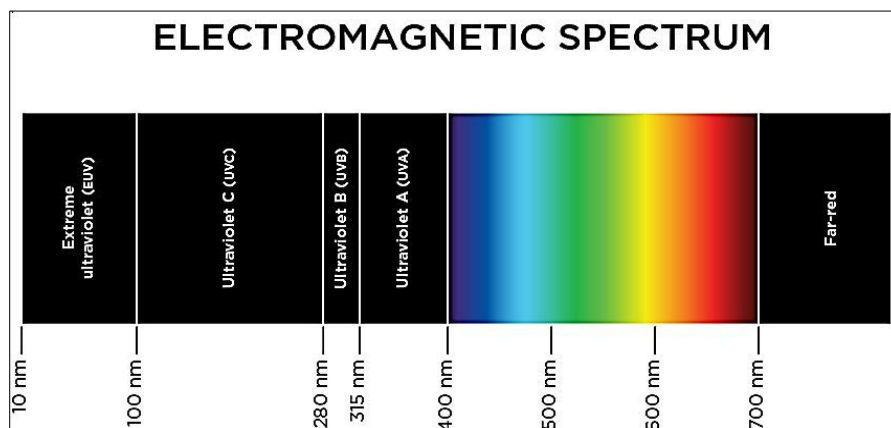


Fig 1: PAR ranges between 400-700 nm in visible range

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Table 1: Effects of Different LED Light Spectra on Plant Growth and Flowering

S.No.	Light Source (LED)	Peak Wavelength (nm)	Spectra	Absorption centres	Effects	References
1.	Blue	480 nm	Blue (visible)	cryptochromes	Height reduction, followed by increase in thickness of leaves. Dealy of flower bud initiation	Głowacka, B. (2004) ^[1]
2.	Red	660 nm	Red (visible)	Phytochrome red (Pr)	Promotes stem elongation, early flowering, higher production of photosynthates, increases flower biomass	Kong <i>et al.</i> (2018) ^[2]
3.	White	400-700 nm	Broad spectrum (visible)	Blue, green and red wavelength	Normal vegetative growth followed by flowering, not effective for flower programming	Vereshchagin <i>et al.</i> (2024) ^[3]
4.	Red+Blue (80:20)	450&600 nm	PAR (visible)	Chlorophyll a, b, phytochromes and cryptochromes	Higher plant height, increased leaf number, early flower bud initiation and uniform flowering	Gao <i>et al.</i> , (2022) ^[4]

Table 2: Effect of Different Light Sources on Plant Growth and Bud Formation Stage

Light treatment	Observed response in plants	Interpretation
Control (CFL / Tube light)	Normal vegetative growth, slow bud formation, no leaf burn	Broad spectrum with low PAR intensity; safe but less efficient for growth regulation
Blue LED light	Compact plants, short internodes, delayed bud initiation	Blue light maintains vegetative phase; suppresses elongation via cryptochrome action
Red LED light (high intensity, no dimmer)	Rapid elongation, leaf yellowing, marginal leaf burn	Excess red light caused photoinhibition and stress when intensity is uncontrolled
Red + Blue LED grow light (with dimmer)	Balanced vegetative growth, healthy leaves, early and uniform bud formation	Optimal spectrum with controlled intensity supports physiological transition to bud stage

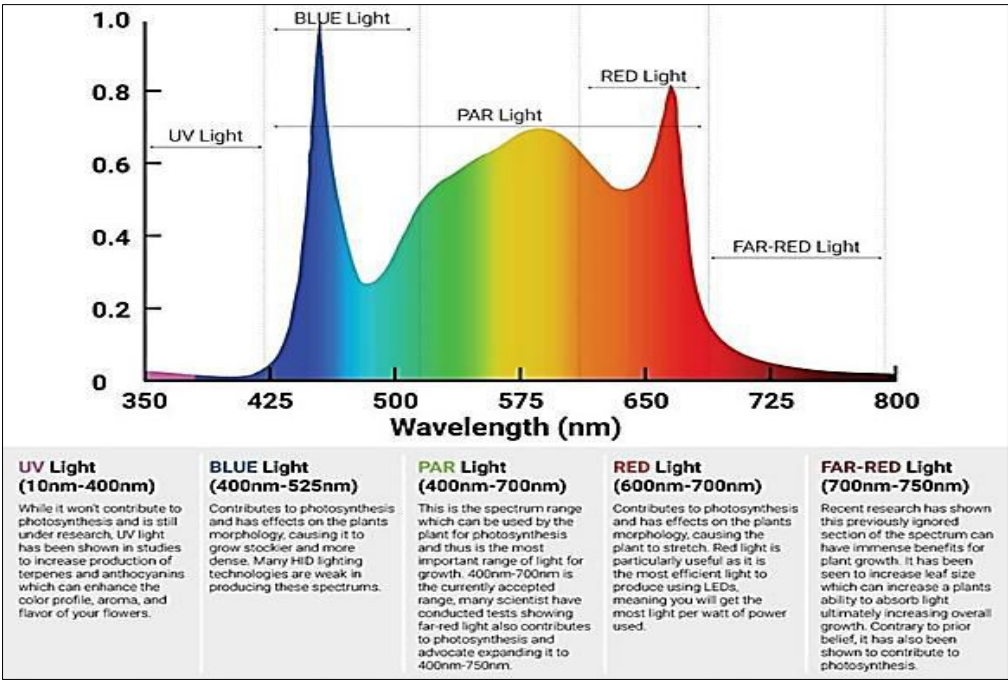


Fig 2: Effects of different light spectra as described by Harman *et al.*, 2021

Still, many existing LED-based growth chambers face challenges related to uneven light distribution, inadequate thermal management, and limited scalability. There is a need for growth chamber designs that integrate optimized LED layouts, effective heat dissipation mechanisms, and automated environmental control systems. The objective of this study was to design and develop a modular LED-based plant growth chamber and to evaluate its performance in terms of spectral light distribution

2. System Design and Development
2.1 Architecture of the Growth Chamber

The developed growth chamber has external dimensions of 5m ×1m ×1m (L × W × H). The chamber structure was fabricated using insulatedplywood painted white for a reflective inner surface to enhance light utilization. An upwards slidable front door allows visual monitoring of plants. Plants were kept in wooden trays also painted white to enhance light absorption



2.2 LED Lighting System Design

The lighting system was designed using brick type LEDs with peak wavelengths at 450 nm (blue) and 660 nm (red), supplemented with neutral white LEDs. The LED chambers were as follows: 100% red, 100% blue, 80% red+20% blue, 100% white and fluorescent light.

LEDs were mounted on aluminum-core circuit boards and arranged in a grid pattern to ensure uniform illumination across the growing area. The total rated power of the lighting system was 220 W.



2.2 Dimmer function

A light dimming mechanism was also incorporated by using a simple step-type regulator to achieve light spectrum

measured in $\mu\text{mol m}^{-2} \text{s}^{-1}$ (PAR Electric) at four different levels at the plant canopy. The details are given in the table.

Table 3: Indicating different PAR levels achieved during O (open chamber) and C (closed chamber) stages

Levels (at plant canopy)	PAR Electric ($\mu\text{mol m}^{-2} \text{s}^{-1}$)							
	80% Red+20% Blue LED		100% Blue LED		100% Red LED		100% White LED	
	O	C	O	C	O	C	O	C
1	46	52	58	13	49	55	161	178
2	107	113	78	99	91	108	198	215
3	125	131	105	137	106	123	227	248
4	164	185	146	184	145	163	292	316

2.3 Light Uniformity

PPFD measurements were conducted at 5 different points across the growth area using a quantum sensor 3415 Fieldsout™. The uniformity coefficient was calculated as the ratio of minimum to average PPFD. The average PPFD achieved at canopy level was $212 \mu\text{mol m}^{-2} \text{s}^{-1}$, with a uniformity coefficient of 0.69, indicating satisfactory spatial light distribution.

2.4 Thermal Management System

Heat generated by the LED modules was dissipated using axial cooling fans. Temperature sensors mounted near the LED boards monitored thermal conditions to prevent overheating. The thermal management system maintained temperatures within safe operating limits, ensuring stable light output and prolonged lifespan of LEDs.

2.7 Novelty of the Proposed Design

The proposed growth chamber integrates a modular LED layout and improved light diffusion strategy. Compared to conventional research chambers, the system offers enhanced

spectral flexibility and ease of customization in terms of LED lights.

3. Materials and Methods

3.1 Experimental Setup

The experiment was conducted inside the growth chamber situated at Centre for protected cultivation technology, IARI (New Delhi) in an enclosed laboratory environment with ambient temperature ranging from 22 °C to 28 °C. All sensors were calibrated prior to the study. PPFD was measured using a calibrated quantum sensor placed at canopy height. Spectral distribution was recorded using a portable spectroradiometer. Temperature and relative humidity were recorded within the chamber over a 24-hour period to evaluate spatial and temporal stability. Chrysanthemum (*Chrysanthemum morifolium*) cv. Zembla was selected as the model crop. Plants were grown for 15 days under a photoperiod of 15 h light and 9 h dark. Growth parameters including plant height, leaf number, and time for bud induction were recorded.

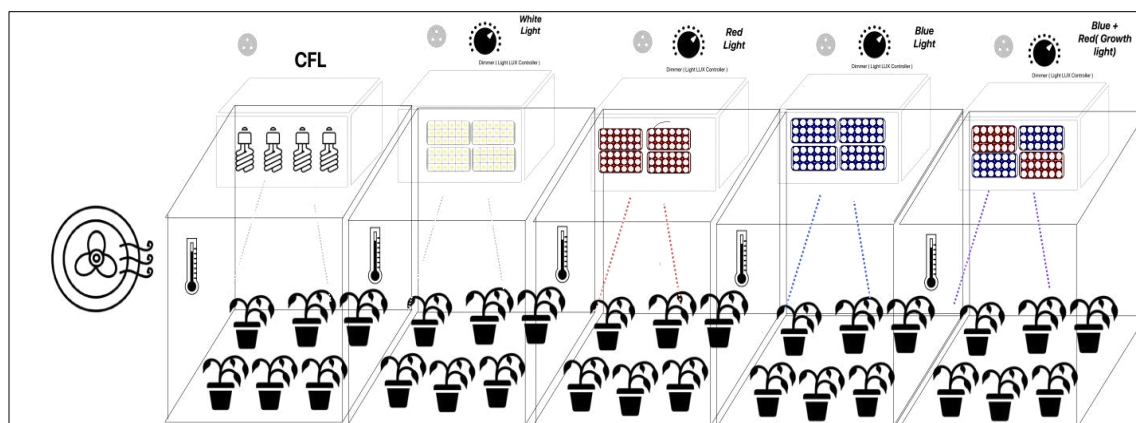


Fig Prototype for the LED/CFL growth module[®]

4. Results

4.1 Optical Performance: The lighting system maintained consistent spectral output throughout the experimental

period. Variations in PPFD across the growing area remained within acceptable limits.



4.2 Plant Growth Response

Table 1 demonstrates that all the results obtained were statistically significant. The maximum plant height (59.76 cm) was observed in treatment 80R: 20B LED at 45 days after planting in chrysanthemum cv. Zembla, while a significant decrease was observed in treatment with blue LED (45.84 cm) among all other treatments. A significant increase in stem length was observed with the effect of different LED lights and combinations. Similarly, number of leaves also demonstrated an increase with the increase in number of days after planting. Leaf number was highest at 80R: 20B LED (19.4) at 45 days after planting among the other treatments. On contrary, least progression in number of leaves (control) was observed with white LED treatment (14.8). Also, excessive exposure to red LED impacted stress and leaf burn-like symptoms, while blue light maintained vegetative growth. The best bud formation was achieved under red-blue LED grow-light along with dimmer control, which outperformed fluorescent light by providing higher efficacy for plant growth devoid of excessive heat or burn effects.

5. Discussion

Height elongation was also demonstrated by Kim *et al.* (2004) [10] where highest plant growth in chrysanthemum plantlets (in- vitro) was achieved highest under RB treatment. Stem elongation is promoted/inhibited by different synergistic interactions occurring among blue and red light receptors which can vary with plant species. Shimizu *et al.* (2006) [6] have reported a 60% inhibition in stem elongation in chrysanthemum using blue LEDs and have suggested the method as an alternative to growth retarding chemicals, which is consistent with our findings.

Zhiyu *et al.* (2007) [7] have also reported similar results in chrysanthemum cv. Reagen where growth inhibition by blue LEDs was observed. The RER (relative elongation) rate was decreased used a high intensity irradiation of blue light. Cryptochrome receptors from blue light are primarily responsible for regulating stem elongation. Since we have used a higher percentage of Red LED lights (80%) in the combination to blue (20%) which resulted in better growth parameters. Red light has been seen to affect photomorphogenetic responses, thus affecting growth by influencing the red and far-red ratio (Sager *et al.*, 1997) [8]. Increase in number of leaves might be as an outcome of increase in carbohydrate and protein biosynthesis, providing optimum conditions for leaf primordial initiation, under the influence of supplemental RB lighting system. Thus, resulting in production of more number of leaves. These results were also supported by Macedo *et al.* (2011) [9] in *Alternanthera*, where number of leaves were produced more under blue fluorescent light compared to other light treatments. Kim *et al.* (2004) [10] also suggested that leaf area was the highest under RB lights in chrysanthemum plantlets, because of cell expansion induced by artificial lights. The duration required for flower bud induction in plants subjected to various light treatments was recorded at the stage of full development. The results were statistically significant for each of the treatments. An increase in the time for flower bud induction was noted with the application of artificial lighting (Table 6). The longest duration for flower bud induction (102.6 days) was recorded in the blue LED treatment. In contrast, the combination of 80% red and 20% blue LED treatment resulted in the shortest induction time (66.6 days) compared to other treatments. Nissim-Levi *et al.* (2019) [11] noted inhibition of flower bud formation in

three chrysanthemum cultivars when exposed to blue LED light. The rate of flowering inhibition associated with blue LED light is influenced by the length of the light exposure.

Additionally, the levels of the CmFTL3 gene are also affected by the use of LEDs. However, Singh *et al.* (2019)^[12] have reported an earlier bud induction using blue LEDs.

Table 4: Effect of Different Light Treatments on Plant Growth Parameters and Flower Bud Induction

Treatments	Height (cm)	Number of leaves	Time taken for flower bud induction (days)
Fluorescent	52.34	15.20	82.2
Red	55.68	18.80	82.2
Blue	45.84	14.80	102.6
80R: 20B	59.76	19.40	66.6
White	54.38	15.60	91.2
CD 0.05	1.69	1.03	4.23
S.E(m) ±	0.57	0.35	1.43

Conclusion

A modular LED-based plant growth chamber was successfully designed and evaluated for physical parameters and flowering behavior of potted chrysanthemum plants. The system demonstrated effective spectral control and uniform light distribution. Hence, it can be concluded that the developed growth chamber is suitable for a small-scale plant research under containers/pots using multi-levelled dimming mechanism. This would result in customized plant spectra at plant canopy levels which can be further utilized for different crop models for further evaluation. Future scope for such module could be an integration of CO₂ enrichment units, or inclusion of far-red/UV lights for additional studies.

Future prospects

Modern luminous technologies, particularly hue-based options can be exploited for further experiments in future with respect to combination effect and intensity. A dimmer function with hue control mechanism can be effectively utilized for such plant experiments in future. Such customizations can be done based on plant species, and also reflection pattern of leaves (thickness and texture). A RGB camera can be integrated with such model to manage hue setting in artificial lights. Thus, PAR based effects on plant growth can be effectively studied and utilized for further plant experiments.

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