

# Optimizing Photosynthesis Active Radiation, PAR: Creating Stable Light Environments for Indoor Farming using reflector

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## Abstract

Agriculture has evolved to become more innovative in parallel with technology advancements, as seen by the rise in demand for food that meets strict quality requirements and has a high nutritional value. One example of this is the development of vertical farming (VF). Without relying on seasonality to affect output, VF is a competitive system for sustainable food production that minimizes the need for land, natural resources, and labor in agriculture. It may be built at any time and wherever in the world. When it comes to VF, light is the most crucial component to take into consideration. Production increases dramatically when artificial light, especially LED lighting, replaces sunlight. A sophisticated kind of precision farming known as "plant factories" involves growing every crop in carefully regulated conditions with exact lighting, humidity, temperature, and nutrient levels. However, the previous study used experiments to assess PAR levels, light intensity distribution, and the ways in which these variables influenced plant growth parameters. The results demonstrate that strategically positioned reflectors significantly increase PAR in the plant canopy, leading to more consistent and higher-quality yields. Through the use of reflectors, this study will optimize photosynthesis active radiation, or PAR and also create stable light environments for indoor farming.

## 1. Introduction

Malaysia's agricultural landscape is undergoing significant changes, prompting increased research focus on indoor farming techniques. Traditional agricultural practices in Malaysia have faced challenges like resource-intensive processes, limited arable land, and unpredictable weather patterns. Sustainable agriculture solutions are becoming increasingly crucial to address these issues. Photosynthesis, the fundamental process driving plant growth, relies on light absorption within the Photosynthesis Active Radiation (PAR) range. In Malaysia, where sunlight is abundant but not always consistent, understanding and optimizing PAR is essential for reliable and efficient crop production. This has led to the rise of indoor farming, which utilizes Controlled Environment Agriculture (CEA) technologies as an innovative solution. The controlled environment of indoor farms allows for

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precise regulation of environmental factors, including light, to create an optimal growth environment. While Malaysia benefits from natural sunlight, indoor farming often integrates artificial lighting systems to supplement or replace sunlight, particularly in urban or controlled environments. Researchers have long investigated the relationship between light quality and plant growth and development. LED lighting, with its energy efficiency and spectral customization capabilities, is widely used to tailor PAR exposure based on specific crop needs. Uneven PAR distribution across the growth bed is a common issue in indoor farming facilities, despite the use of LED lights. This unevenness can lead to inconsistent photosynthesis rates among crops, resulting in uneven growth and potentially compromising overall yield and crop quality. The current PAR distribution in the indoor farming facility at Test Rig in Centre for Energy and Industrial Environment Studies (CEIES), UTHM, is uneven, aiming to achieve a target range of 150-200  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . However, this uneven distribution can lead to delayed maturity, stunted growth in areas with insufficient light, and increased susceptibility to diseases, altered flavor and texture, and leaf tip burn in areas with excessive light.

This study has two main objectives focused on optimizing plant growth conditions within an indoor farming facility. The first objective is to determine the efficacy of LED lighting in assisting plant growth. LED technology offers several potential benefits for indoor farming, including energy efficiency and the ability to tailor the light spectrum to specific plant needs. By analyzing plant growth responses under LED lighting, we can gain valuable insights into its effectiveness compared to traditional methods. Next, it is to improve the consistency of Photosynthetically Active Radiation (PAR) at the growth bed using reflectors. PAR refers to the specific wavelengths of light that plants can use for photosynthesis, the process that fuels their growth. Uneven PAR distribution within the growth bed can lead to inconsistencies in plant development. This study aims to evaluate the impact of reflectors in directing and focusing light, ultimately achieving a more uniform PAR level across the entire growing area.

The significance of this study lies in its potential to contribute to the advancement of indoor farming practices. By investigating the effectiveness of LED lighting and the use of reflectors to optimize PAR distribution, we can provide valuable information for growers. This includes:

- Understanding the growth-promoting capabilities of LED lighting
- Optimizing PAR distribution for consistent plant development
- Establishing best practices for monitoring PAR in indoor farms

## 2. Materials and Methods

### 2.1 Experimental Setup and growth conditions

Butterhead lettuce seeds were germinated for a maximum of 48 hours at room temperature. Following germination, the seeds were sown in seedling sponges and grown hydroponically using the Nutrient Film Technique (NFT) within a controlled environment conditions (Test Rig, CEIES) measuring 4ft x 3ft x 8ft. The chamber was maintained at a constant temperature of 23°C, relative humidity of 83%, and CO<sub>2</sub> concentration of 385 ppm, as monitored by a JD-3002 air quality tester. Each level of the four-tiered Test Rig contained 30 gutter holes, allowing for a total of 120 lettuce plants per planting cycle. The City Farm nutrient solution was used throughout a single planting cycle, with its concentration ranging from 900 to 1000 ppm as measured by a HI98130 Combo instrument from Hanna Instruments. The plants were then exposed to four different light treatments before harvest, which occurred 27 days after sown.

### 2.2 Light-quality treatments

The Test Rig, a four-tiered controlled environment room, was utilized for this experiment. Each level was planted with butterhead lettuce. The light treatments employed varied across the levels:

Level 1: Plants received a photoperiod of 14 hours of light followed by 10 hours of darkness.

Level 2: Plants were exposed to a photoperiod of 7 hours of light and 5 hours of darkness.

Level 3: A more complex photoperiod was implemented here, consisting of alternating cycles of light and darkness: 5 hours on, 3.5 hours off, followed by 4 hours on, 3 hours off, and concluding with 5 hours on and 3.5 hours off.

Level 4: Plants received the shortest photoperiod of the experiment, with 3.5 hours of light followed by 2.5 hours of darkness.

All levels were equipped with three LED panels positioned at a constant distance of 25 cm from the top of the lettuce-planted gutters. Light intensity measurements were conducted using a QUANTUM PAR METER AZ 8583. The full spectrum of the white LED light source was then used on the website 'waveform lighting' to convert the measured Photosynthetically Active Radiation (PAR) values to Photosynthetic Photon Flux Density (PPFD). Specifically, level one recorded an average of 298.03 micromoles per square meter per second ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ), level two recorded an average of 281.2  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , level three recorded an average of 310.57  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , and level four recorded an average of 283.29  $\mu\text{mol m}^{-2} \text{s}^{-1}$ .

### 2.3 Plant Growth Measurements and Morphology

Following the 27-day planting period, plant growth data was collected from each level of the Test Rig. This involved analysing 12 individual plant samples per level, resulting in a total of 48 samples across all four levels. For each sample, plant height and diameter were meticulously measured. Additionally, PAR readings were obtained at 9 designated points within each level, totalling 36 samples PAR measurements across the entire Test Rig. Data collection occurred at daily intervals throughout the 27-day growth period. Plant growth rate was calculated by dividing the change in plant diameter by the change in plant height over the measured period.

### 2.4 Measurement of PAR Reading and Plants' Diameter

Plant diameter and photosynthetically active radiation (PAR) readings are two significant measurements used in indoor farming to assess plant growth. It is essential to comprehend how these factors relate to one another to maximize the productivity of plants and optimize lighting conditions. Generally, a specialist instrument such as the QUANTUM PAR METER AZ 8583 is used to obtain PAR readings. Instead of focusing only on light that is the same level as the gutter, these meters are put at certain locations throughout the growth bed to capture the light levels that the plants themselves experience. Another significant growth indicator is plant diameter. A MITUTOYO DIGITAL CALIPER is frequently used to get measurements, offering the best way to evaluate plant progress.

## 3. Result and Discussion

### 3.1 Plant morphology and growth characteristics



Figure 1: Butterhead for level 1 with photoperiod 14/10 hours and with reflector



Figure 2: Butterhead for level 2 with photoperiod 7/5 hours and without reflector



Figure 3: Butterhead for level 3 with photoperiod 5/3.5/4/3/5/3.5 hours and with reflector



Figure 4: Butterhead for level 4 with photoperiod 3.5/2.5 hours and without reflector

Plant weight data was collected from four samples per level under four different light treatments: 14/10 hours (Figure 1), 7/5 hours (Figure 2), 5/3.5/4/3/5/3.5 hours (Figure 3), and 3.5/2.5 hours (Figure 4). Interestingly, while butterhead lettuce grown under 14/10 and 5/3.5/4/3/5/3.5-hour light treatments (Figures 1 & 3) appeared heavier in these figures, overall plant growth, as measured by weight, was greatest under the 7/5-hour treatment (Figure 2). In addition to weight, the butterhead lettuce grown under the 7/5-hour light treatment (Figure 2) also displayed superior morphological characteristics (shape and form).

### 3.2 Growth rate of PAR Reading and Plants' Diameter

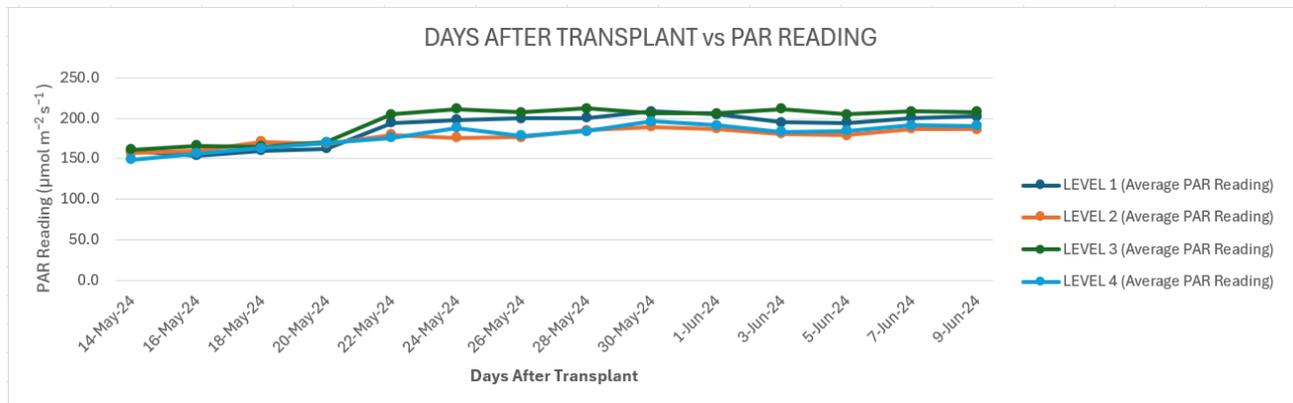


Figure 6: The growth rate for butterhead according to PAR Reading

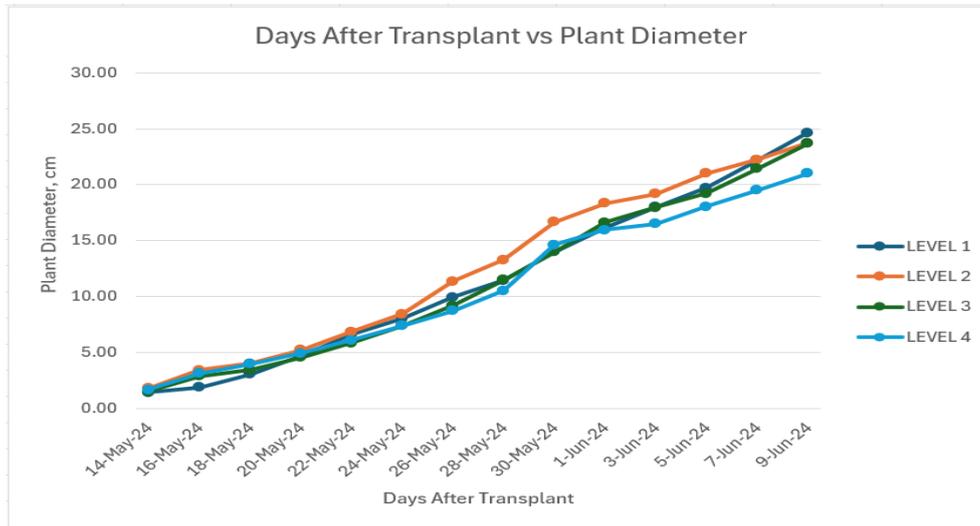


Figure 7: The growth rate for butterhead according to plants' diameter

The two graphs above show the average diameter and PAR reading of butterhead lettuce over a 27-day period following transplanting, under four different light treatments for each level. Over the course of the 27 days, the average plant diameter in each of the four treatments for four levels appeared to have increased gradually, according to this diameter growth trend. This suggests that every group has grown overall. It is challenging to discern any noticeable variation in plant diameter between the treatments during the observation period. There is typically some overlap between the numbers for each light treatment group. Based on the average daily growth rate, level 2 for light treatment appears to promote the fastest growth in butterhead lettuce among the four treatments investigated over this 27-day period.

### 3.3 Number of leaves and the height of plants for Butterhead

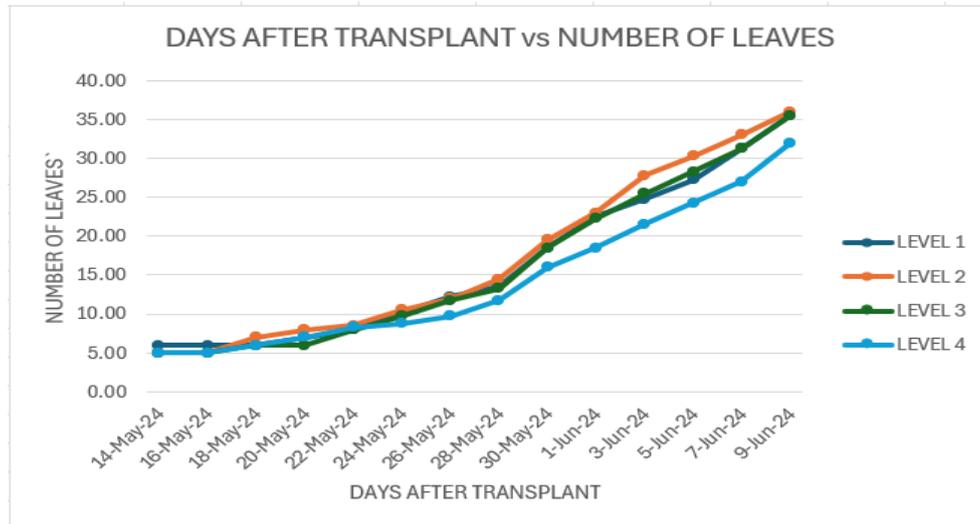


Figure 8: The average number of leaves for Butterhead

Based on the graph above presents that average number of leaves increases gradually in the four distinct photoperiods. A photoperiod refers to the duration of light and darkness a plant experience daily. According to the graph, the highest average number of leaves is observed in level 2 which is 36 pieces, followed by in level 1 and 3 while the lowest is seen in level 4 at 32 pieces. Similarly, the highest average height of butterhead that shows in graph below which is recorded in level 2 at 7.78 cm, and the lowest in level 4 at 5.22 cm.

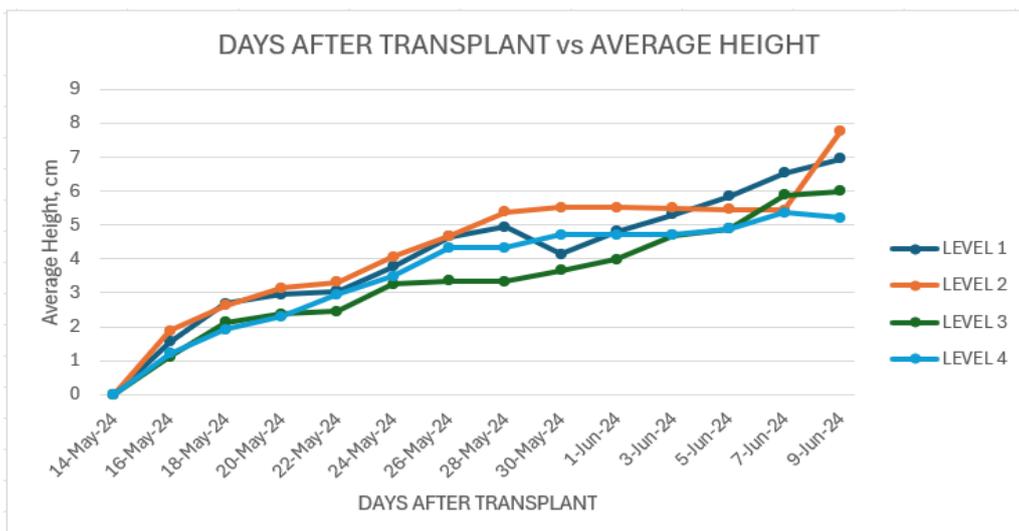


Figure 8: The average height for Butterhead

### 3.4 Discussion

#### 3.4.1 Effect of light in indoor farming

Deeper sections of each story in a vertical farm, which are frequently in a controlled environment (CE) and protected from external environmental conditions, are not exposed to direct sunlight due to their higher ceiling, apart from parts close to the building face [1]. When direct sunlight cannot reach the lowest layers of the soil, photosynthesis and the plant’s normal growth are hampered. Similarly, LED lighting in indoor farming diffracts light away from the growth bed, reducing photosynthetically active radiation (PAR) in units of  $\mu\text{mol m}^{-2} \text{s}^{-1}$  needed for plant growth.

#### 3.4.2 Light Spectrum

Plants thrive in the visible light spectrum, which is between 400 and 700 nanometers (nm). This spectrum, known as photosynthetically active radiation (PAR), powers photosynthesis, the process by which plants convert light energy into food-producing carbohydrates. However, there are differences among the hues in PAR. The wavelengths that are most important for photosynthesis are red and blue. Light that is not visible to the human eye also matters. Certain lower UV wavelengths can aid in plant growth and defense even if high UV light dosages (280–400 nm) can be harmful. Even when a plant blooms and how tall it grows can be affected by far-red light (700–780 nm). Although a single PAR hue can initiate photosynthesis, plants often respond best to a light display that emulates sunlight. This means that, depending on the needs of the plant, there should be a good balance of red and blue light, as well as possibly some green and far-red light [2].

#### 3.4.3 Optimal Light Quality

Plant Factory with Artificial Lighting (PFAL) systems rely heavily on light quality to maximize plant development. LEDs provide a flexible option for agriculture in regulated environments, but it is important to consider their spectrum output. The five wavelength bands that make up the light spectrum radiated by the LEDs used in photo facial lights (PFALs) are ultraviolet (UV), blue, green, red, and far-red. It is noteworthy that certain LED arrangements might not produce ultraviolet or far-red light. In [3] Red to far-red light and blue to red light ratios have been found to be important determinants of plant quality in PFALs. Researchers must experiment with different combinations of these color bands to get the best light quality for crops.

#### 3.4.4 Light Duration

Precise regulation of light has tremendous benefits for agriculture in controlled environments. Growers may optimize plant growth, output, and quality while reducing energy consumption by precisely adjusting light intensity, duration (photoperiod), and spectrum. The proper level of light intensity, expressed in PPFD, is essential. In growth is impeded by insufficient light, but adequate light promotes photosynthesis and sugar production. Likewise, it is crucial to provide the proper photoperiod according to the requirements of each plant. In conclusion, the optimal light for plant development is obtained by concentrating on the light spectrum between 400 and 700 nm, which is the most photosynthetically active [5]. Growers can enhance harvestable output and

improve the nutritional quality of their crops while lowering energy costs through optimum lighting methods by proactively controlling these light parameters.

#### 3.4.5 Dark Cycles in Indoor Farm

We investigated the effects of dividing up light exposure into brief, hourly cycles on plant anthocyanin synthesis. We altered the light's on/off pattern while maintaining the same level of brightness. The plants produced more anthocyanin the longer the light was on relative to the off time (higher light time ratio). Plants produced 70% more anthocyanin when the light was on for 75% of the time as opposed to when it was on continuously. They produced 45% more when the light was on 50% of the time. [6]

Plants respond to light duration in a variety of ways; botanists classify plants into "long-day" and "short-day" kinds. Based on the ideal amount of daylight hours required for healthy growth and development, these are categorized according to their photoperiodic requirements.[4]

Artificial lighting methods are used in greenhouse settings when natural sun radiation might not be sufficient to meet the photosynthetic needs of plant species. To guarantee ideal growth and development, these methods offer more lighting. In greenhouse environments, the strategic placement of reflectors combined with the economical and suitable application of lighting systems yields two benefits. It is firstly useful for carefully regulating light levels to make sure they meet the photosynthetic requirements of the plants under cultivation. The second benefit of using reflectors is that they improve the greenhouse's ability to heat. [4]

## 4. Conclusion

Photosynthesis-active radiation (PAR) in indoor farming conditions was studied at Universiti Tun Hussein Onn Malaysia with the goal of optimizing PAR utilizing reflectors. Using reflectors and four distinct light treatments with variable photoperiods, butterhead lettuce was grown for the experiment. According to the findings, carefully placing reflectors raised PAR levels in the plant canopy by a significant amount, producing more reliable and superior produce. According to the research, the following average PAR values were observed for the various light treatments: An average of 298.03  $\mu\text{mol m}^{-2} \text{s}^{-1}$  was observed by Level 1, 281.2  $\mu\text{mol m}^{-2} \text{s}^{-1}$  by Level 2, 310.57  $\mu\text{mol m}^{-2} \text{s}^{-1}$  by Level 3, and 283.29  $\mu\text{mol m}^{-2} \text{s}^{-1}$  by Level 4.

36 samples total from the whole Test Rig were collected at the nine predetermined sites in each level. The butterhead lettuce grown under the 7/5-hour light treatment (Level 2) exhibited superior morphological traits and the largest overall growth, as evaluated by weight, according to plant growth measures. Level 2 had the most leaves on average—36 pieces—followed by Levels 1 and 3, while Level 4 had the fewest leaves—32 pieces. In a similar vein, butterhead lettuce's average height peaked in Level 2 at 7.78 cm and decreased in Level 4 to 5.22 cm. There are various factors that can lead to difficulties for salad growth. These include low germination rates, carbon dioxide, and fertilizer.

Out of the four treatments that were examined over a 27-day period, Level 2 stimulated the fastest growth rate, as seen by the change in plant diameter and height over the observed period. This implies that the growth of butterhead lettuce in the study's-controlled environment was especially benefited by the photoperiod, which consisted of 7 hours of light and 5 hours of darkness.

In conclusion, it was discovered that the deployment of a 7/5-hour photoperiod and the use of reflectors to optimize PAR dispersion were useful tactics for boosting butterhead lettuce growth and productivity under indoor farming settings. These results emphasize the significance of balanced lighting and aid in the establishment of best practices for indoor farming.

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