APPLICATION OF REFLECTOR FOR LIGHT EMITTING DIODES GROWTH LIGHT FOR MULTI-TIER HYDROPONIC RACKING SYSTEM IN CONTROLLED ENVIRONMENT STRUCTURE

Khairul Anuar bin Shafie
Muhammad Syahiran Afieff Bin Azman
Mohd Daniel Hazeq Bin Abdul Rashid
Engineering Research Centre,
MARDI Headquarters,
Persiaran MARDI-UPM,
43400 Serdang Selangor

Mohammad Abid bin Ahmad
Horticulture Research Centre,
MARDI Headquarters,
Persiaran MARDI-UPM,
43400 Serdang Selangor

ABSTRACT

The multi-tier hydroponic planting system in controlled environment structure is a new method in the production of vegetable crops to deal with food safety issues. The controlled environment structure requires artificial lighting to replace natural light and Light Emitting Diode (LED) growth lights lamps have been used. However, the use of LED lamps is one of the factors that increase energy consumption in controlled environment structure. In this study, two types of reflective materials were used with LED lamps to identify its effect to growth light. The LED lamp used is a MARDI formulation red-blue spectrum LED. Reflectors made of white painted steel and Aluminum material have been used for this experiment. LED lamps without reflectors (control) have been used as reference data. Each rack level has 5 rows x 2 columns of LED lamps. The Li-Cor 180 Spectrometer was used to measure Photosynthetic Photon Flux Density (PPFD) (µmol/m²/s) and the measurement was carried with PPFD data taken under the lamp and between the lamps. Based on the result of the reflective material with a red-blue spectrum lamp, the average PPFD reading for the white painted steel material is higher than the Aluminum material and the control which is PPFDmax 367.3 µmol/m²/s compared to PPFDmax Aluminum 340.1 µmol/m²/s and PPFDmax control which is 318.8 µmol/m²/s. In next research, the energy saving study will be done by designing new reflector for red-blue spectrum LED lamp and reducing the number of LED lights for each level of the planting racking system.

Keywords: Light Emitting Diode (LED), Growth Light, Photosynthetic Photon Flux Density (PPFD), reflector

INTRODUCTION

Controlled environmental structures, such as greenhouses and plant factories, have revolutionized agriculture by allowing precise control over environmental factors. One of the main components that need to be considered in the application of this system is the lighting on the plants. The artificial lighting sources can be used in controlled environmental structures to optimize plant growth, increase yield and extend the growing season. As the demand for sustainable farming methods increases, optimizing the efficiency of energy use has become a priority in the horticulture industry as an alternative to traditional lighting systems, such as fluorescent lights that use high energy. The use of LED lights can increase the efficiency of energy use with low-power components. With the addition of light-reflecting components (reflectors), the lighting coverage of LED lamps on plants can be expanded and reduce the number of LED lamp units per square meter.

HORTICULTURAL LED LIGHTING

Plants in a controlled environment structure require artificial lighting to meet the plant's needs. Light is a fundamental factor that affects the growth, development, and productivity of plants through the process of photosynthesis (Yang, Song and Jeong, 2022). It provides the energy needed for the conversion of carbon dioxide and water into glucose and oxygen (Yahia et al., 2019). Different wavelengths of light affect various aspects of plant physiology, such as flowering, fruiting, and morphology (Ouzounis, Rosenqvist and Ottosen, 2015). By manipulating lighting, plant growth can be regulated to meet specific needs. LED lighting technology has become popular in the horticulture industry due to its advantages over traditional lighting sources such as fluorescent lamps or high-pressure sodium lamps. LED lighting is energy efficient, uses less power and has a longer lifespan. Additionally, it emits a specific range of light wavelengths, which can be adjusted to match the optimal spectral range for plant growth and ensure maximum photosynthetic efficiency. The ability to manipulate the light spectrum makes LED lighting very adaptable for a variety of horticultural applications.

Picture 1 shows examples of reflectors that are available in the market, which are steel plate material reflectors with white paint and aluminum plat material reflectors. These reflectors are used in lighting evaluations for plant growth and compared to LED lights without reflectors.

Figure 1: LED light reflector types

a) Steel plat material reflector with white paint

b) Aluminum plat material

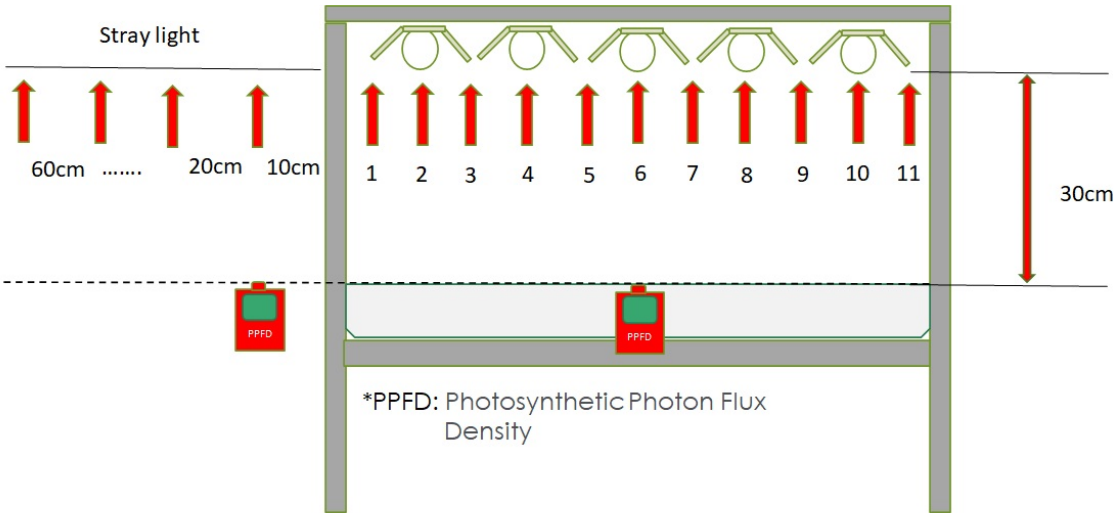
METHOD

PPFD stands for Photosynthetic Photon Flux Density, and it is a measure of the amount of photosynthetically active radiation (PAR) that reaches a certain surface area in a unit of time. In horticultural lighting, PPFD is an important measurement used to evaluate the intensity and quality of light received by plants.

PPFD is measured in units of micromoles per square meter per second (µmol/m²/s). It measures the number of photons in the PAR range (wavelengths between 400 and 700 nanometers) that reach a given area per second. PPFD provides an indication of the amount of light available for photosynthesis, which is the process by which plants convert light energy into chemical energy to drive growth and development.

For the measurement of light under the plant shelf, a spectrometer LI-180 (Li-Cor Environmental, USA) was used. LI-180 measures the wavelength between 380nm to 780nm, spectral bandwidth of 12nm (half bandwidth) and measurement range between 1 to 3,800 µmol/m²/s. For this experiment, PPFD measurements were performed on a planting rack without plants. The PPFD measurement is taken at 11 measurement points with a height distance of 30 cm between the spectrometer and the LED lamp and reflector as in Figure 2. Measurements are taken under the LED lamp and between the LED lamp and the reflector. For the measurement of stray light or deviation light, i.e. the light outside the rack, plant growth light readings are taken at a distance of every 10 cm up to 60 cm with a reading interval of 10 cm.

Figure 2: Design of light measurement of plant growth in the raised plant rack



Th multi-tier planting rack has seven levels and each level has 10 LED light tubes and is fitted with reflectors of different materials. Aluminum reflectors were installed on the 1st floor, steel type reflectors with white paint on the 2nd floor and no reflectors were installed on the 3rd floor shelves as a control for comparison between different types of reflectors.

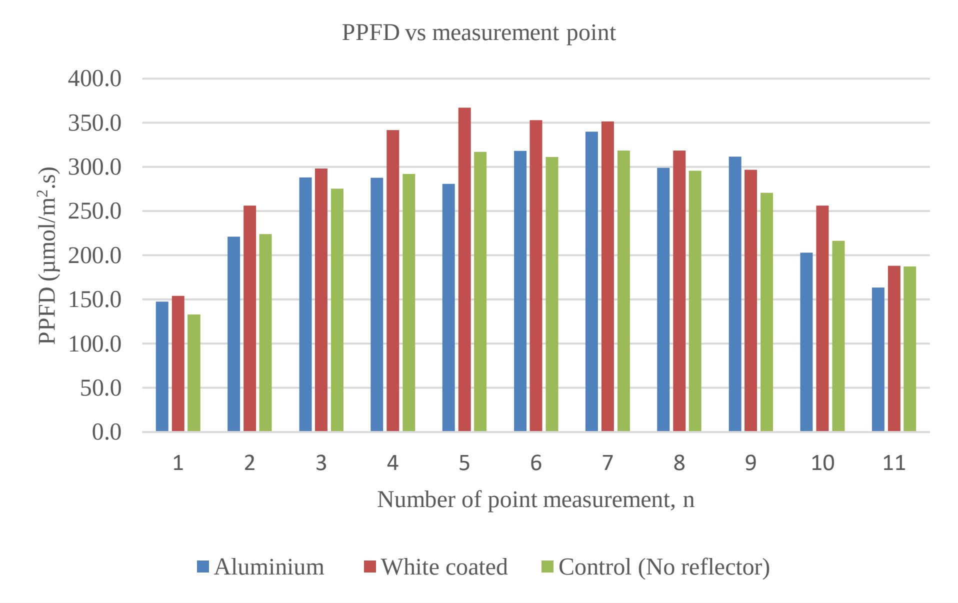
Data analysis for red-blue spectrum LED reflectors

Table 1 shows the tabulated data obtained from Li-Cor measurement with respect to different type of reflector materials. A total of 11 measurement points were recorded for each type of reflector in three locations, namely at the front of the rack, the middle of the rack and the back of the rack. The average reading for these 11 measurement points has been obtained and plotted in a bar graph of Figure 3. The lowest average PPFD reading was recorded at measurement point 1 which is on the edge of the shelf with an average PPFD reading of 133 to 154 µmol/m²/s (aluminium, plate white painted steel and control). The highest average PPFD reading was recorded at measurement point 5 which is between the two LED lamps which is 367.3 µmol/m²/s (iron white paint). This PPFD value is sufficient for leafy vegetable crops that require a PPFD reading of up to 250 µmol/m²/s. Based on the comparison between the types of reflectors, it was found that the steel plate with white paint gives a high PPFD reading compared to the aluminum reflector with a difference in PPFDmin reading 6.23 and PPFDmax 86.3 µmol/m²/s.

Table 1: Photosynthetic Photon Flux Density (PPFD) (µmol/m²/s) data with respect to reflector materials

ALUMINIUM												
POINT		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
PPFD (LI-COR)	**LEFT**	140.0	234.5	321.4	328.8	318.5	336.0	371.6	345.9	299.3	239.3	170.2
	MID	155.4	215.2	266.5	244.2	295.1	322.3	321.6	276.2	359.6	244.9	168.9
	RIGHT	148.0	214.0	276.2	290.1	229.2	296.9	327.2	275.0	275.9	125.4	151.5
	Ave	147.8	221.2	288.0	287.7	280.9	318.4	340.1	299.0	311.6	203.2	163.5
METAL												
POINT		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
PPFD (LI-COR)	**LEFT**	166.1	272.2	318.4	371.4	392.4	371.2	377.6	350.7	300.4	273.1	178.3
	MID	153.6	247.8	303.9	335.3	353.3	351.5	292.3	261.2	273.8	218.9	187.7
	RIGHT	142.4	248.5	272.9	318.8	356.1	335.9	384.7	344.2	316.7	276.4	198.2
	Ave	154.0	256.2	298.4	341.8	367.3	352.9	351.5	318.7	297.0	256.1	188.1
NO REFLECTOR												
POINT		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
PPFD (LI-COR)	**LEFT**	132.5	229.2	287.4	303.7	324.3	333.8	338.2	306.3	282.2	234.5	185.6
	MID	138.7	228.9	278.6	299.8	316.4	318.3	338.2	317.2	278.4	201.1	200.1
	RIGHT	128.0	214.4	260.6	273.0	311.0	281.9	279.9	264.3	251.6	213.7	176.5
	Ave	133.1	224.2	275.5	292.2	317.2	311.3	318.8	295.9	270.7	216.4	187.4

Figure 3: Measurement of plant growth illumination, PPFD under RB LED lights in hydroponic plant racks



Data analysis for stray light red-blue LED lights

Figure 4: Stray light measurement of planting rack

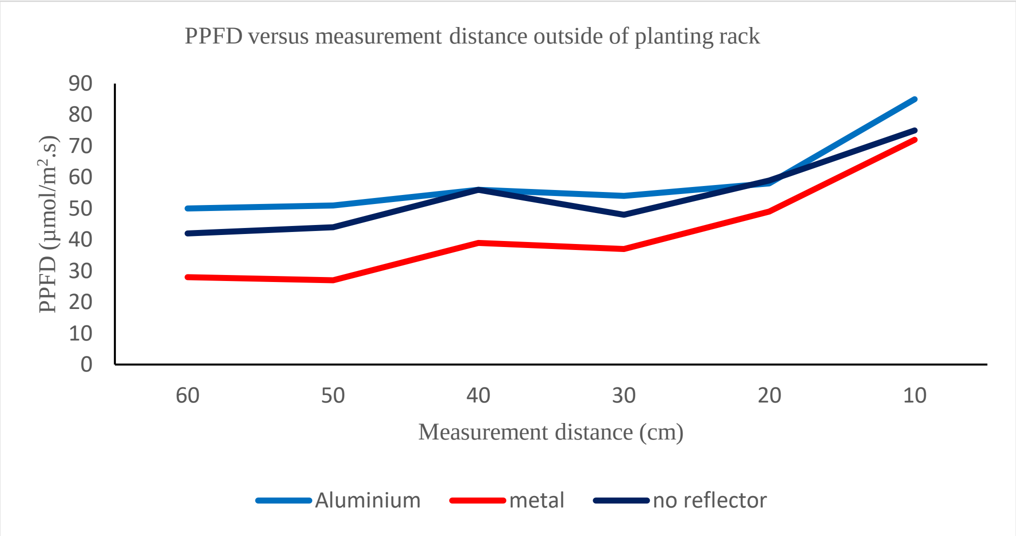


Figure 4 shows the stray light measurement of LED light from three different sources, light from steel plate reflector, aluminium reflector and control (no reflector). The measurements were performed to determine stray light produced by horticultural LED lights and to determine either the stray light affects the plants growth on adjacent shelves. A total of six additional measurement points were taken for light measurement outside the rack with a measurement point interval of 10cm. It was found that average PPFD readings were measured up to 40 µmol/m²/s. Based on the light requirements of plant growth, the minimum PPFD required is 100 µmol/m²/s (Zou et al., 2020) for leafy vegetables. As such, the reflected light produced by LED lights is not sufficient to influence the plants growth on adjacent shelves.

CONCLUSION

Evaluation has been done on application of reflector with respect to red-blue spectrum LED lights in order to optimize lighting on leafy vegetable crops. Two types of reflectors are used which are aluminum plates and white painted steel plates. The red-blue spectrum LED light have an average PPFD of 78 µmol/m²/s. The results show that steel plates with white paint increase the illumination of LED lamps by an average of 1.1 times compared to LED lamps without reflectors with a maximum PPFD value of 367.3 µmol/m²/s. Reflectors from aluminum plates also increase the illumination of LED lamps by an average of one time compared to LED lamps without reflectors but less by 10% when compared to steel plate reflectors with white paint.

For LED lamp lighting outside plant shelves, PPFD readings recorded are between 40 µmol/m²/s to 70 µmol/m²/s with a maximum distance of 60 cm from the edge of the shelf. The LED light outside this shelf does not affect the growth of the plants on the adjacent shelf because the minimum illumination required by the plants is within 100 µmol/m²/s.

Acknowledgement

The author would like to express his sincere appreciation to MARDI management, Director and research team members from Engineering Research Centre and Horticulture Research Centre. The project is funded by the Ministry of Agriculture and Food Security (KPKM) under RMKe-12 Development Project entitled "Pembangunan Sistem Pengeluaran Tanaman Berinovasi Untuk Jaminan Makanan, Kelestarian Dan Kesejahteraan Masyarakat (P21400010170503)".

References

Ouzounis, T., Rosenqvist, E. and Ottosen, C.-O. (2015) 'Spectral Effects of Artificial Light on Plant Physiology and Secondary Metabolism: A Review', *HortScience: a publication of the American Society for Horticultural Science*, 50, pp. 1128–1135. doi:10.21273/HORTSCI.50.8.1128.

Yahia, E. M. *et al.* (2019) 'Photosynthesis', *Postharvest Physiology and Biochemistry of Fruits and Vegetables*. Woodhead Publishing, pp. 47–72. doi: 10.1016/B978-0-12-813278-4.00003-8.

Yang, J., Song, J. and Jeong, B. R. (2022) 'Lighting from Top and Side Enhances Photosynthesis and Plant Performance by Improving Light Usage Efficiency', *International Journal of Molecular Sciences*, 23(5). doi: 10.3390/ijms23052448.

Zou, T. *et al.* (2020) 'Optimization of artificial light for spinach growth in plant factory based on orthogonal test', *Plants*, 9(4). doi: 10.3390/plants9040490.