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การประยุกต์ใช้แผ่นกระจายแสงและไดโอดเปล่งแสงให้แสงพืช โดยใช้รูเจาะเป็นตัวกระจายแสง

Application of Light Guide Plate and Light Emitting Diode for Plant Illumination by Using Drilling Holes as The Light Scatter

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บทคัดย่อ

แผ่นกระจายแสงแบบวงกลมและมีไดโอดเปล่งแสงแบบเส้น (strip LED) ถูกติดที่เส้นรอบวงถูกประดิษฐ์ขึ้นเพื่อใช้เป็นแสงเทียมให้แสงพืช แผ่นกระจายแสงถูกทำขึ้นจากแผ่นอะคริลิกใส Polymethyl methacrylate (PPMA) ซึ่งมีความทนทานต่อสภาพอากาศแผ่นกระจายแสงที่มีขายอยู่นั้น พื้นผิวด้านใดด้านหนึ่งจะถูกกัดให้มีลายเส้น (V-Cutting) หรือพิมพ์ลายจุดที่ผิว (dot printing) หรือผสมทั้งลายเส้นและพิมพ์ลายจุด หรือการเติมอนุภาคขนาดเล็กเข้าไปในแผ่นกระจายแสง ลวดลายเหล่านี้ที่สร้างขึ้นมาที่พื้นผิวจะทำหน้าที่กระจายแสงให้ทั่วทั้งแผ่นและนำแสงออกสู่ผิวด้านหน้าของแผ่นกระจายแสง ในวิธีการพิม์ลายจุด หมึกสีขาวจะถูกพิมพ์เป็นลายจุดลงบนพื้นผิวด้านใดด้านหนึ่ง จุดที่พิมพ์เหล่านี้จะทำหน้าที่กระจายแสงจากไดโอดเปล่งแสง ถึงแม้ว่าวิธีการพิมพ์ลายจุดจะเป็นวิธีการที่มีราคาถูกและทำได้รวดเร็วกว่าวิธีกัดลายเส้น แต่ยังมีจุดอ่อนที่หมึกที่ใช้พิมพ์ยังมีประสิทธิภาพในการกระจายแสงไม่ดีนัก ทำให้แผ่นกระจายแสงที่ใช้วิธีการพิมพ์ลายจุดให้แสงสว่างไม่ทั่วทั้งแผ่น (บริเวณกลางแผ่นจะมีแสงสว่างน้อย) ไม่เหมาะกับงานเช่น backlighting ซึ่งต้องมีความสว่างมาก ในการวิจัยนี้เทคนิคการเจาะรูที่พื้นผิวให้มีลักษณะเป็นเลนส์เว้าทั่วทั้งแผ่นกระจายแสงถูกใช้แทนวิธีการพิมพ์ลายจุด รูที่เจาะจำทำหน้าที่กระจายแสงทั่วทั้งแผ่นกระจายแสงและรูที่เหมือนเลนส์เว้าจะทำให้แสงกระจายออกสู่ผิวด้านหน้า แผ่นกระจายแสงที่มีลวดลายของรูเจาะดังกล่าวจะสามารถผสมแสงสีแดงและแสงสีน้ำเงินจากไดโอดเปล่งแสงแบบเส้นที่ติดอยู่ที่ขอบเส้นรอบวงของแผ่นกระจายแสง ด้วยอัตราส่วนแสงสีแดงต่อแสงสีน้ำเงินที่เหมาะสมเพื่อให้แสงต่อพืช โดยทั่วไปแล้วแผงไดโอดเปล่งแสงสำหรับปลูกพืชที่มีจำหน่ายนั้น อัตราส่วนแสงสีแดงต่อแสงสีน้ำเงินจะถูกกำหนดตายตัวโดยผู้ผลิต ผู้ใช้ไม่สามารถปรับเปลี่ยนอัตราส่วนนี้ได้ แต่แผ่นกระจายแสงที่ประดิษฐ์ขึ้นนี้ ผู้ใช้สามารถออกแบบอัตราส่วนแสงสีแดงต่อแสงสีน้ำเงินตามความต้องการของพืชที่ปลูก ความเข้มแสงที่ได้จากแผ่นกระจายแสงที่อัตราส่วน (แดง : น้ำเงิน) ต่าง ๆ ถูกวัดด้วยเครื่องวัดความเข้มแสงเปรียบเทียบกับกรณีสีแดงล้วน และสีน้ำเงินล้วน ต้นอ่อนข้าวสาลีถูกใช้เป็นพืชทดลองให้แสงด้วยแผ่นกระจายแสงกรณีต่าง ๆ

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น้ำหนักของต้นอ่อนข้าวสาลีและความเข้มข้นของสารคลอโรฟิลล์จากต้นอ่อนข้าวสาลีถูกตรวจวัดเพื่อยืนยันความเป็นไปได้ของการประยุกต์ใช้งานแผ่นกระจายแสงเพื่อให้แสงต่อพืช

ABSTRACT

Circular shape acrylic Light Guide Plate (LGP) attached with strip Light Emitting Diode (LED) at circumference as artificial lighting for plant illumination is fabricated. LGP is an acrylic panel typically made from pure Polymethyl methacrylate (PPMA), resin which is extremely transparent, highly weather resistance and easily purchased. On the top or the bottom of the panel, a matrix of lines can be etched, called V-Cutting, dots can be printed, a combination of both, or particulates are added into the panel itself. The purpose of all methods is to direct light out the front of the panel. Dot printing is a matrix of fine dots which is printed onto the LGP using diffusive ink. These dots help scatter the light emitted from the light source. Dot printing is a quicker and cheaper process than V-cutting however, not always the desired method. The major disadvantage of dot printing is that ink is less effective at refracting light and therefore not as bright. Many backlighting applications require a very bright light that dot printing cannot accomplish. A simple technique to scatter the light from the light source through LGP by making a matrix of drilled holes as the concave lens all over LGP panel is proposed. This technique with LGP can be used to mix red and blue strip LED light source with appropriate ratio between red and blue colour to be artificial lighting for plant illumination. In general, artificial LED lighting for plant illumination, the ratio between red and blue color is always fixed by the manufacturer of LED panel. The user cannot adjust the fixed red and blue ratio. With LGP technique, the user can design the ratio of red and blue color LED by selecting the number of red LED and blue LED to attach at the circumference of LGP. In this experiment, the light intensity of various ratios of mixed red color and blue color are measured with light spectrum instruments compared to the light intensity of unmixed red color and unmixed blue color. With this artificial lighting for plant illumination, wheatgrass sprouts grown result and their chlorophyll extraction results are examined to confirm the possibility in using this technique.

คำสำคัญ: แผ่นกระจายแสง ไดโอดเปล่งแสง การสกัดสารคลอโรฟิลล์

Keywords: Light Guide Plate, Light Emitting Diode, Chlorophyll Extraction

INTRODUCTION

All plants require light for photosynthesis: the process that plant uses light to change carbon dioxide and water into carbohydrates. Oxygen and water are released as a byproduct of photosynthesis. A low light plant such as wheatgrass sprouts requires little light to no direct light. But it still needs sufficient light for starting seeds indoors. LED artificial lighting for growing plants indoors is readily available and easy to come by especially online shopping. But those LED lighting panels are not intentionally dedicated designed for specific plants. They are designed for general plants rather than specific plants. Light Guide Plate (LGP) attached with strip LED is interesting to be used as artificial lighting for wheatgrass sprouts low light plants.

Light guide plates (LGP) have served in lighting applications for over three decades. All LGP are a transparent plastic panel made from pure Poly methyl methacrylate (PMMA) resin. Also known as acrylic, acrylic glass or plexiglass. PMMA or acrylic has the properties: extremely transparent, lightweight, shatter-resistant, an alternative to glass. On the top or the bottom of the LGP panel, various pattern structures can be made such as a matrix of lines can be etched, called V-cutting, dot can be printed, or combination of both V-cutting and dot printing or laser engraving are added onto the panel to direct light out to the front.

Light emitting diode (LED) are placed on one or multiple edges of the LGP panel, the light runs into the panel and is reflected from the panel by the pattern on the bottom side of the panel. Nowadays, lighting technology, called lighting panels which is a product that uses LGP plus LED, is generally used for home lighting, lighting walls, advertisement boards and backlighting for display equipment. In this article, the technique that use LGP plus strip LED as a lighting source for growing wheatgrass sprouts indoors is proposed.

Momin *et al*. (2024) reported that blue LED light had a positive effect on the growth parameters and nutrient concentration of wheat and lentil sprouts and red LED light proved to be more effective in increasing the growth characteristics and nutrient concentration of wheat and lentil sprouts. Bartucca *et al*. (2020) reported that red light increased the total amount of chlorophyll in wheatgrass. Yanga *et al*. (2018) reported that chlorophyll production failed under red irradiation alone while blue and red irradiation are required for the synthesis of pigments. However, all these studies were conducted under artificial LED lighting within laboratory settings, rather than utilizing LED lighting panels in real-world environments. In this work, LGP with drilled holes as the light scatter are fabricated and this study aims to propose a technique of using LGP plus LED as artificial lighting to illuminate wheatgrass sprouts indoors and investigate the best mixing ratio of blue light and red light that creates the highest chlorophyll concentration as the product of wheatgrass sprouts juice.

MATERIALS AND METHODS

Figure 1 shows the diagram of artificial lighting for plant illumination made from acrylic LGP attached with strip LED at the edge of LGP and covered with mirror at top surface. The matrix of drilled holes all over LGP panel are drilled with an electric drill (Figure 2) will scatter the light through the center of LGP.

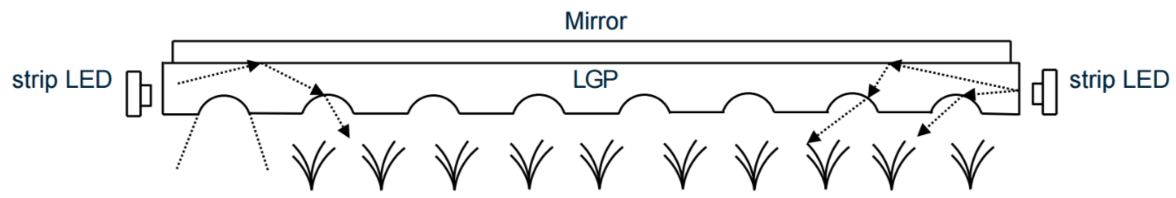


Figure 1 Diagram of LGP artificial lighting for plant illumination.

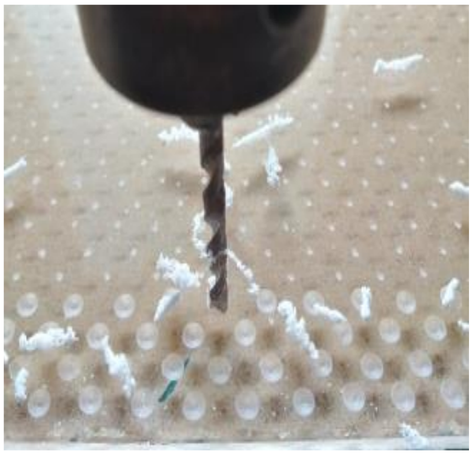


Figure 2 Drilling holes by electric drill.

Instead of using white color ink dot printing as in commercial LGP, drilled holes can scatter the light due to the refractive index of acrylic is different from the refractive index of the air in drilling holes. When the light travels through different mediums, the light is refracted. Therefore, a lot of drilling holes at the surface of acrylic panel are the light scatter of LGP as same as dot printing in commercial LGP. The shape of each hole looks like the concave lens in which it diverges the light out the front of the panel.

Table 1 Specification of blue and red strip LED attached to LGP.

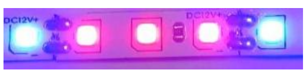
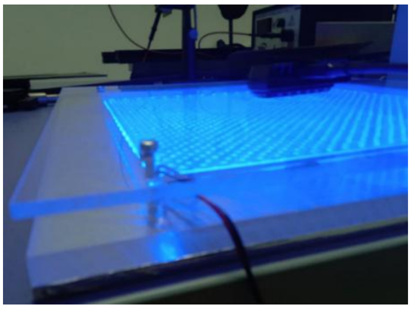
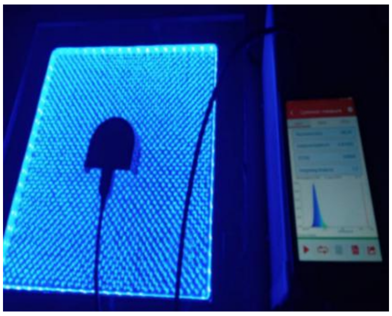
SMD 3528 Strip LED (Blue vs Red)	Apply Voltage	Power Consumption	Lumen output
	12 V	4.8 W /meter	480 lumens/meter
	12 V	4.0 W /meter	420 lumens/meter

Table 1 shows the specification of SMD 3528 strip LED used in this experiment.

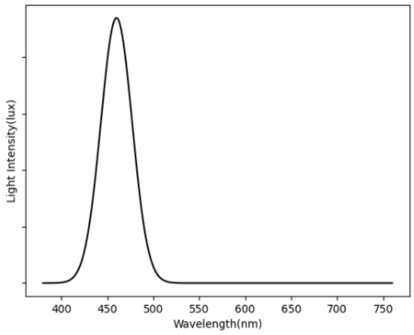


(a)



(b)

(c)



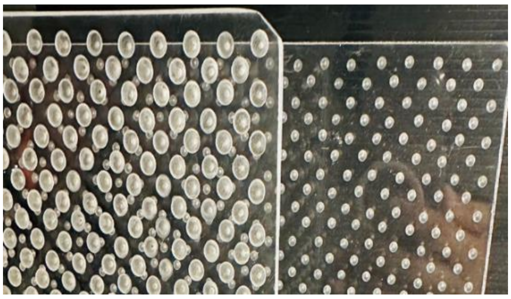
(d)

Figure 3 Measurement of LGP light intensity; Measure at 1 cm above LGP (a), Measure at the center of LGP (b), Light sensor (c), Light spectrum of blue color LGP (d)

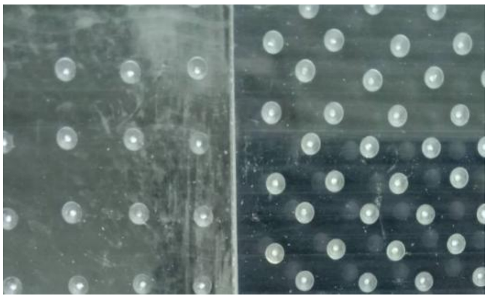
Figure 3 shows the light intensity of LGP lighting measured with Spectral Irradiance Colorimeter (SPIC-300AW EVERFINE), the light sensor located 1 cm above the surface of LGP.

Preliminary Experiment

At first, the square shape (30 cm × 30 cm) acrylic LGP is fabricated to study the scattering results with various drilling hole diameter, 10 mm adjacent hole distance compared to shrink distance (7 mm), and single layer compared to double layers drilled holes (bottom and top layer). The blue color strip LED is attached to all 4 sides of LGP (120 cm). The mirror is attached to the backside to reflect the light out the front of the panel. The light intensity (Lux) is measured at the center, and the other points close to LED light source as shown in the following pictures.



(a)



(b)

Figure 4 Two different drilled holes diameters and two different adjacent distances; 5 mm Ø and 3 mm Ø drilled holes (a), 3 mm Ø 10 mm distance and 7 mm shrink distance (b)

Figure 5 Double layers drilled holes, 3 mm Ø.

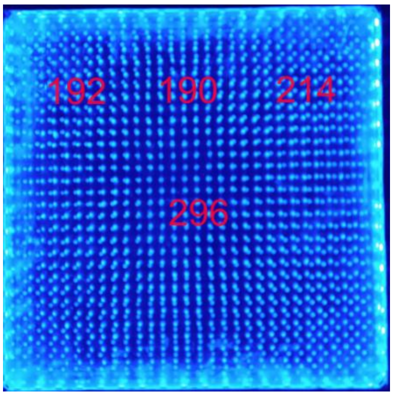


Figure 6 3 mm Ø and 10 mm. distance.

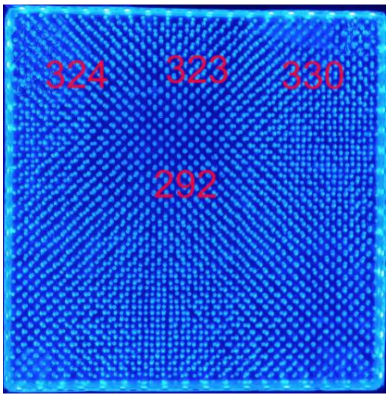


Figure 7 3 mm Ø and 7 mm shrink distance.

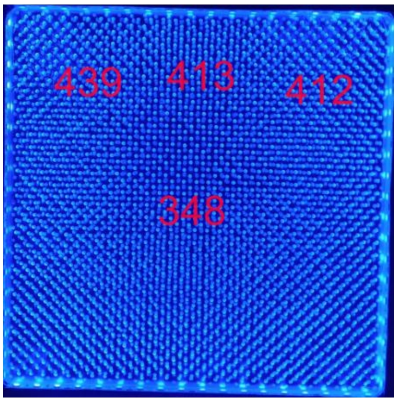


Figure 8 double layers 3 mm Ø drilled holes.

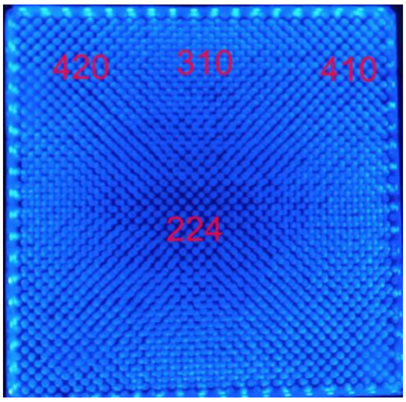


Figure 9 5 mm Ø and 7 mm shrink distance.

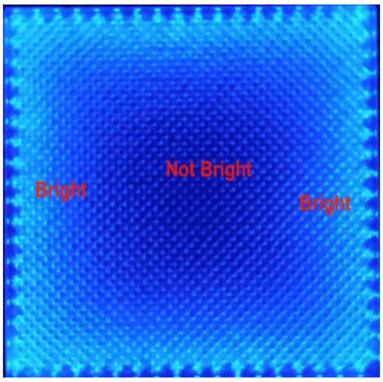


Figure 10 5 mm Ø (paper cover instead of mirror).

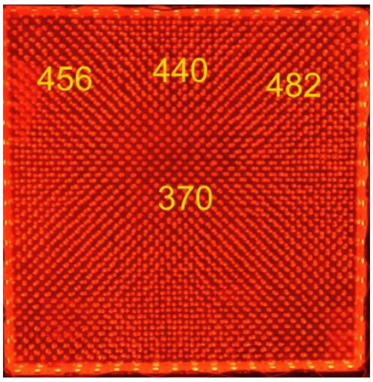


Figure 11 3 mm Ø and 7 mm shrink distance.

In all cases of different diameter drilled holes and different adjacent hole distance, the light is not bright at the center of LGP, because it far from the LED light source. At the corner of the square LGP panel, the light is always brighter than the other portion because it is close to both sides of LGP edges which strip LED are attached. When the adjacent hole distance shrink, LGP give more brightness result. And LGP with bigger drilled holes, the more brightness can be obtained compared to LGP with smaller drilled holes. Figure 10 Illustrates square LGP with 5 mm diameter drilled holes and 7 mm shrink adjacent hole distance and intentionally covered with white paper instead of mirror, it shows that the central portion is not bright enough due to more light emitted through the bigger drilled holes at portion near LED light source. Then, less light can scatter to the central area. In Figure 11, the same result occurs if red LED is replaced instead.

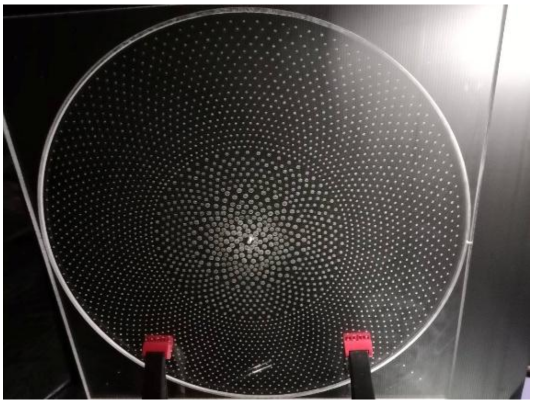


Figure 12 Circular shape LGP.

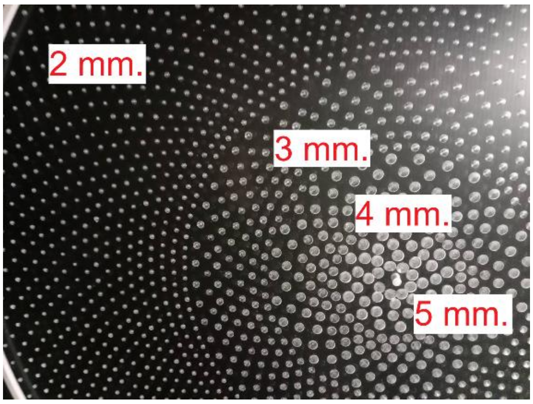


Figure 13 2, 3, 4 and 5 mm Ø drilled holes.

To cope with the problem of unbalanced brightness between the corner area and other portion area of square shape LGP, the circular shape LGP is used instead because it does not have corner. Therefore, after strip LED is attached at circular LGP edge, all the light from strip LED will direct to the center of the LGP and the brightness will be balance or equivalent around the circular area. The circumference of circular LGP is 120 cm.

The drilled holes are drilled by electric drill with 2 mm diameter in circular pattern as illustrated in Figure 12 and 13. The number of drilled holes in the most outer circle is 120 holes and the next inside circle has also 120 holes. Therefore, the adjacent hole distance along the circle will decrease as the circle becomes small circle. As the adjacent hole distance decreases, the number of drilled holes per area will increase, Therefore, the light illuminance will increase. To balance the brightness all over the circular shape LGP, it is needed to increase the drilled holes diameter as well. Because the brightness is inversely proportional to the distance, the distance from the LED light source increases and the brightness decreases. Then, the drilled holes diameter is increased to be 3 mm, 4 mm and 5 mm, respectively, to compensate for the poor brightness at central area, as shown in Figure 13.

RESULTS AND DISCUSSION

Blue color strip LED, red color strip LED, mixed different ratio of blue and red color: (B1R1, B2R1 and B1R2) are attached to the edge of circular shape LGPs. The light intensity of each LGP lighting is measured with Spectral Irradiance Colorimeter (SPIC-300AW EVERFINE) at the center of LGP (1 cm. above the surface of LGP) as shown in the following figure and summarized measured light intensity data is presented in Table 2.

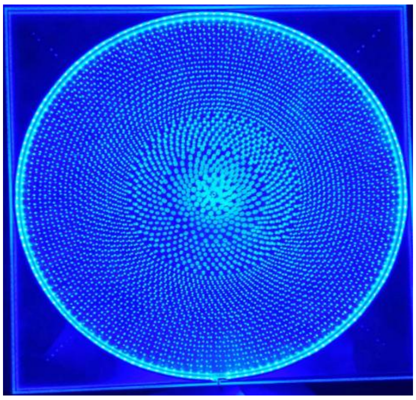


Figure 14 Blue color LGP.

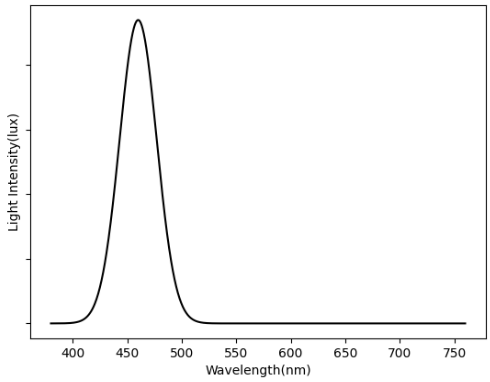


Figure 15 Blue color Light Spectrum (420 lux).

Figure 16 Red color LGP.

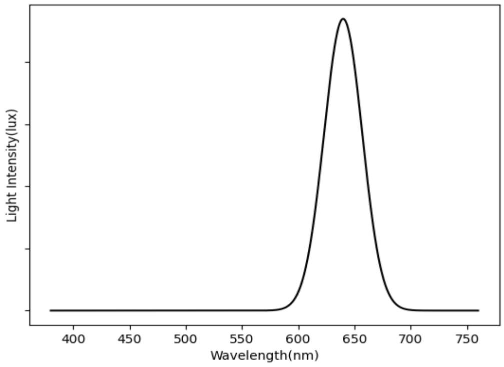


Figure 17 Red color Light Spectrum (350 lux).

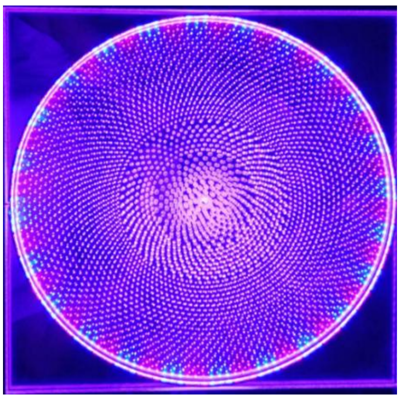


Figure 18 B1R1 LGP.

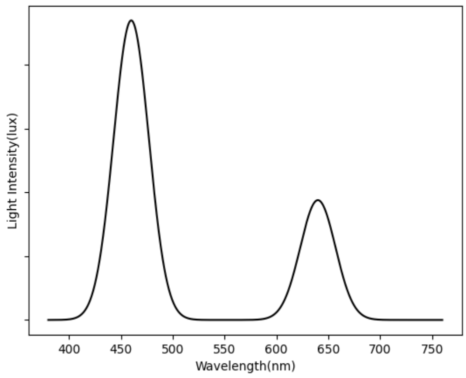


Figure 19 B1R1 Light Spectrum (383 lux).

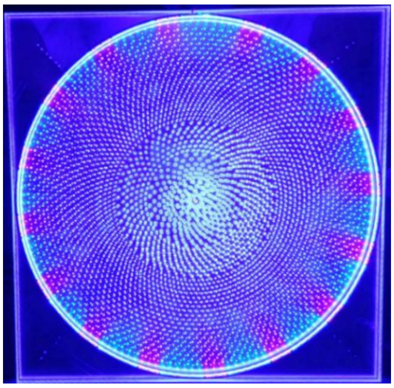


Figure 20 B2R1 LGP.

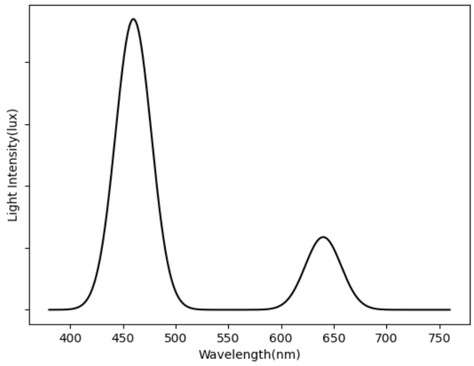


Figure 21 B2R1 Light Spectrum (395 lux).

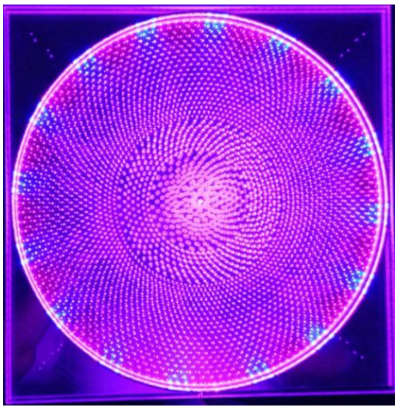


Figure 22 B1R2 LGP.

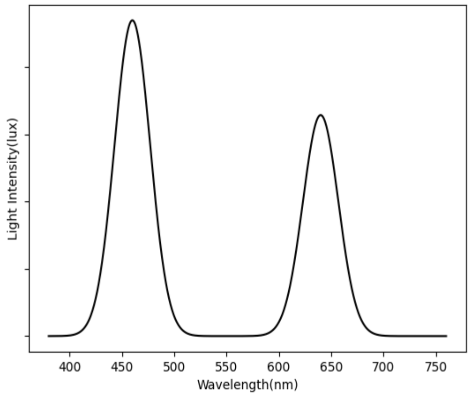


Figure 23 B1R2 Light Spectrum (367 lux).

In Figure14 to Figure 17, it shows that the blue color LED gives out the light intensity (420 lux) more than that of the red color LED (350 lux) which will be influenced to the light intensity of mixed blue and red LED. In Figure 18 to Figure 23, it also shows that the blue color component has more light intensity than the red color component in all cases of mixed blue and red LED: B1R1(383 lux), B1R2(367 lux) and B2R1(395 lux). B1R1(383 lux) has more light intensity than B1R2(367 lux) because B1R1 has more blue light portion than that of B1R2. B2R1(395 lux) has the most light intensity compared to other mixed blue and red lighting because B2R1 has the most blue light portion.

Wheatgrass sprouts growing

Wheatgrass is selected as a plant to illuminate with the experimental prototype LGP lighting panel for 12 hours a day; because wheatgrass sprouts need low light intensity and the growing time is not more than 10 days to extract chlorophyll as the product. Four hundred grams of wheatgrass seeds is soaked in warm water for 2 hours. Subsequently, after having drained them thoroughly, place them on a surface moistened with a wet cloth for 2 days. All 5 different LGP artificial lighting panels are used to illuminate the light (10 cm. above planting container) for wheatgrass sprouts growing for 7 days (4th day until 10th day), and another one is grown under the sun. All experimental wheatgrass growing are conducted indoors at room temperature and 80% average relative humidity as shown in Figure 24 and Figure 25.

Figure 24 wheatgrass sprouts illumination.

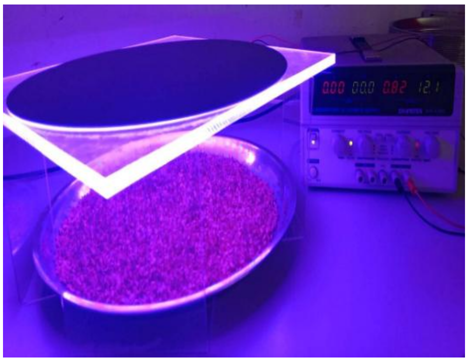


Figure 25 Mixed color wheatgrass sprouts illumination.

Chlorophyll Measurement

After growing for 10 days, Chlorophyll content of wheatgrass leaf in each case of different illumination is measured with The Soil Plant Analysis Development (SPAD) chlorophyll handheld meter in which it analyzed the chlorophyll concentration in SPAD unit and 10 sprouts are measured to obtain average value in each case (Figure 26). The resulting weight of 200 growing wheatgrass sprouts in each case are measured with 4 digits high precision laboratory analytical balance on the 10^{th} day of growing time (Figure 27).

Figure 26 Chlorophyll measurement (SPAD unit).

Figure 27 Weight measurement.

Table 2 Chlorophyll concentration and weight of wheatgrass sprouts (200 sprouts).

Light Illumination	Light Intensity (lux)	Chlorophyll SPAD unit	Standard Deviation of measured chlorophyll	Weight (g) 200 sprouts
Shade-grown	1,200	37.9	0.14142	13.7840
Red	350	32.8	0.10954	10.2796
Blue	420	33.0	0.15491	12.2234
B1R1	383	37.4	0.10954	10.1937
B1R2	367	36.0	0.17320	11.2146
B2R1	395	38.0	0.16733	13.0382

Spectrophotometer Measurement

To confirm the result of wheatgrass chlorophyll concentration from SPAD measurements, spectrophotometer measurements (SPECORD 250 PLUS, analytikjena) are conducted to measure wheatgrass chlorophyll obtained with acetone extraction (10 grams of wheatgrass leaf and 150 ml. acetone). The optical absorption of wheatgrass chlorophyll in all cases is shown in the graph of Figure 28.

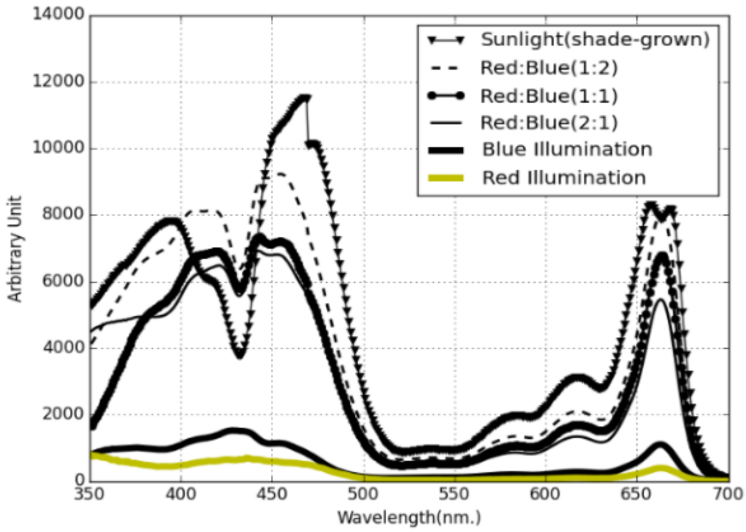


Figure 28 Optical absorption of wheatgrass's chlorophyll.

Experimental Results

Wheatgrass growing weight.

On the 10th day of growing time, all cases of wheatgrass sprouts are harvested for weight measurement and chlorophyll extraction. The result in Table 2. reveal that, all cases of unmixed red colour, unmixed blue colour, mixed red and blue colour illumination, the resulted wheatgrass fresh weight are lower than the weight of wheatgrass grown under the sun (cover with sunshade net). Blue LGP illumination has wheatgrass fresh weight (12.2234 g) more than the case of red LGP illumination (10.2796 g). In all cases of mixed blue and red lighting, B2R1 lighting illumination give out the most growing fresh weight (13.0382 g).

Chlorophyll Concentration

The result of SPAD chlorophyll measurement shows that all cases of mixed red and blue colour illumination have a chlorophyll content more or less equal to the case of shade-grown, which is growing under the sun and covered with sunshade net. While, the cases pure red colour and pure blue colour illumination, their chlorophyll concentration are extremely low. The spectrophotometer graph shows that all cases of mixed red and blue colour illumination have more chlorophyll concentration than that in other cases of pure red colour and pure blue colour illumination. Both resulted measurements of chlorophyll concentration in case of pure red illumination shows that only red illumination cannot bring about productive chlorophyll with is correspond to Yanga *et al.*'s research. They reported that chlorophyll production failed under red irradiation alone while blue and red irradiation are required for the synthesis of pigments. However, all cases of artificial lighting illumination have less chlorophyll concentration compared to that of shade-grown wheatgrass. All mixed blue and red lighting generate more chlorophyll concentration compared to the cases of pure blue and pure red lighting. This corresponds to Bartucca *et al.*'s research who reported that red light increased the total amount of chlorophyll in wheatgrass. Mixed B2R1 illumination generates the most chlorophyll concentration compared to all cases of mixed blue and red artificial lighting. This is new finding from the experiment which demonstrates that there should be enough portion of blue light compared to red light portion to obtain high yield chlorophyll production. Due to available LED lighting panels in electronic shops in which there usually be the ratio of red light more than the ratio of blue light such as 1:2 (B:R) and 1:4 (B:R), This is because blue light always has light intensity more than red light intensity. Therefore, those LED lightings are intentionally designed having red light portion more than blue light portion. According to the experiment, B2R1 lighting causes the most chlorophyll concentration of wheatgrass sprouts, Then LGP with LED can be a positive option for users who can customize the ratio of mixed blue and red light as required.

Because chlorophyll is the photosynthetic pigments in plants that absorb both blue light (400 - 500 nm) and red light (600 - 700 nm), Therefore, blue light and red light are essential for photosynthesis process. Several chlorophylls are known (a, b, c_1, c_2, d and f), The most widely distributed form in terrestrial plants is chlorophyll a. Another one is chlorophyll b which is synthesized from chlorophyll a by the enzyme name chlorophyllide-a oxygenase. Both chlorophyll a and chlorophyll b are light dependent in which they absorb both blue light and red light. Chlorophyll *a* has approximate absorbance maxima of 430 nm and 662 nm, while chlorophyll *b* has approximate maxima of 453 nm and 642 nm This is why mixed blue, and red-light illumination will create more chlorophyll concentration than the case of pure blue-light illumination and the case of pure red-light illumination.

CONCLUSIONS

The lighting panel, fabricated with circular LGP and LED attached to LGP circumference is demonstrated with wheatgrass growing weight and wheatgrass chlorophyll concentration. The resulting experimental data prove that LGP can be used together with LED as an artificial lighting panel for some plant illumination; in which the plant needs less light intensity such as various kinds of green sprouts. The advantage of using LGP together with LED is that blue light and red light from LEDs can mix within LGP before emitting out from the panel to the plant. Therefore, very tiny plant can be illuminated with the same ratio of mixed blue and red lights all over the same planting container. Compare with normal LED lighting panel, blue light and red light are mixed in the air above the plant, Then, some areas are illuminated with more blue proportion and other areas are illuminated with more red proportion. Another advantage is that acrylic LGP has a long-lasting period of use, LED lighting source can be replaced when expired but LGP can be reused for many years.

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