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Effect of LED Wavelength and Power on the Hydroponic Indoor Vegetable Farming

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Abstract In this study, the effect of different light emitting diode (LED) grow light wavelength and power of the LED lights on plant growth were investigated by adopting nutrient film technique of hydroponic indoor vegetable farming. Commercial LEDs are deployed in this work, and the findings benefited the farmers who rely on commercial LEDs. Two phases of plant development were affected differently with different LED wavelength. Color spectrum in this study involves three colors that are red, blue and white in different ratios, providing different wavelength. Budding phase as well as stem and leaf development of the plant shows a great reaction with the highest average width and length of the leaf from 1 red 7 white LED wavelength. Meanwhile, 2 red 3 white LED gives the early starts on the budding phase due to its red light, but the leaf development was the slowest due to the absence of blue lights. The light spectrum from 1 red 7 white has included a strong blue spectrum which helps in the stem and leaf development process. Different LED power with a full spectrum of LED wavelengths has shown an exceptional growth for the plants with highest power of 40 Watts. With full inclusions of red, blue and white spectrum, higher power of the LED helps exponentially especially in the budding phase of the plant.

Keywords LED Grow Light, Wavelength, Power, Hydroponic, Indoor Farming

1. Introduction

Nowadays, smart agriculture or commonly known as smart farming are taking places in the farming sector. Smart farming technologies (SFT) are being used to boost both quality and quantity of agriculture products by utilizing current technologies such as IoT, cloud storage, big data, and mobile devices. The benefits of smart farming include increased productivity, reduced resource consumption, minimized environmental impact, and improved economic outcomes for farmers. By integrating technology and data into traditional agricultural practices, smart farming contributes to more sustainable and efficient agriculture for the future [1]. Agriculture sectors play an important role in ensuring food availability and security ranging from activities such as planting crops, timber and raising livestock. Since 2018, several factors have contributed to food security crisis such as conflict, climate change, and COVID-19 pandemic [2]. In Malaysia, this situation has instead turned into an awareness of producing their own food. This is demonstrated in increase of urban agriculture participations from 18,687 to 40,219 in 2019 and 2020, respectively [3]. The most commonly approach would be urban farming that seen to increase during recent pandemic period.

The most common utilized urban farming methods were hydroponic where the plants were grown in soilless media with their roots directly submerged in nutrient-rich solution [4]. This will allow the plants to focus on the growth more instead of expanding its root system for food up-taking. There are several different systems of hydroponics such as aquaponics, aeroponics, wick system, drip system, ebb and flow, nutrient film technique, and deep-water culture. Meanwhile its plant culture system divided into open and close with open system being more popular albeit not environmentally friendly. In the open system, the nutrient solution is drained after one-time use, whereby close system recycled the water [5]. The implementation of hydroponics agriculture requires a smaller space and allows mass adoption. It also eliminates the constraint of seasonality that allows all year-round crop production. The absence of soil minimizes the incidence of plant diseases and pests, thereby reducing the reliance on pesticides. It also uses less water consumptions compared to field crop that loss water through evaporations [5].

Urban farming was usually done indoor which arises concern about the optimum environment for the produces to grow. This includes concern on the growing lights where using artificial lights on the produces might address this concern. Light emitting diodes (LEDs) offers advantages of narrow light spectrum, low power consumption, and little heat production [6]–[8]. With the LED technology, commercial production and research have increased involving the use of LED in the growth process. Various research investigations have examined crop production under different color LEDs, varying color fluorescent lights, and diverse combinations of these two lighting sources [9]–[11]. Past research has demonstrated the impact of light color intensity on plant growth. The combination of red and blue light has been identified as an effective lighting source for plant development [12] and for promoting plant health [13]. Plants cultured under a red and blue intensity ratio of 1:1 have shown a higher specific leaf area [14]. Although green light was commonly believed to be inactive in promoting plant growth, a study has indicated that high-intensity green LED light is indeed effective in promoting plant growth [10]. This study focuses on investigating the efficiency of indoor farming with different combination colors of red, blue, and white and different wavelength of the LED.

2. Materials and Methods

The hydroponic system in this study consists of several key elements including LED grow light, growing medium, nutrients solutions, and air pump. Figure 1 shows the illustration of the hydroponic system in this study. Adopting the nutrient film technique (NFT), the setup of the system consists of four racks in vertical alignment with a main tank at the bottom to store the water. Water pump was used to supply the nutrient solution into each upper racks and maintaining the oxygen level in the water. The plant used in this study was tatsoi lettuce. Each of the racks comprises with 12 pots areas that were filled with growing medium such as rockwool, coco fiber, or perlite to avoid drifting seedlings into the solutions. This medium also serves porous spaces to hold the oxygen and nutrients to grow. Nutrient solution in this study consists of calcium, nitrogen, magnesium, potassium, phosphor, sulphur, boron, chlorine, copper, iron manganese molybdenum, and zinc. The plants were placed under the light treatments for 12 hours in a day for a total of 30 days. The first cycle on this study uses different combination of wavelengths of light which are 3 red 2 blue 1 white (3:2:1), 1 red 7 white (0:1:7), 2 red 3 white (2:0:3), and 5 red 1 blue (5:1:0). On the second cycle, full spectrum LED light (QGP) with different LED power varies from 8, 16, and 40 W denoted as P8, P16, and P40, respectively. The denoted names are summarized in Table 1. The LED used was a commercially purchased LED grow light. The plant was exposed to LED grow light for 12 hours per day. Two types of nutrient solution were kept constant throughout the study. Each nutrient solution contributed 150 mL for this cycle with the electrical conductivity of the solution being kept within the value of 0.7 μs/cm. Meanwhile, pH value was maintained at 6.86 with the average humidity and temperature of the room at 78% and 29°C.

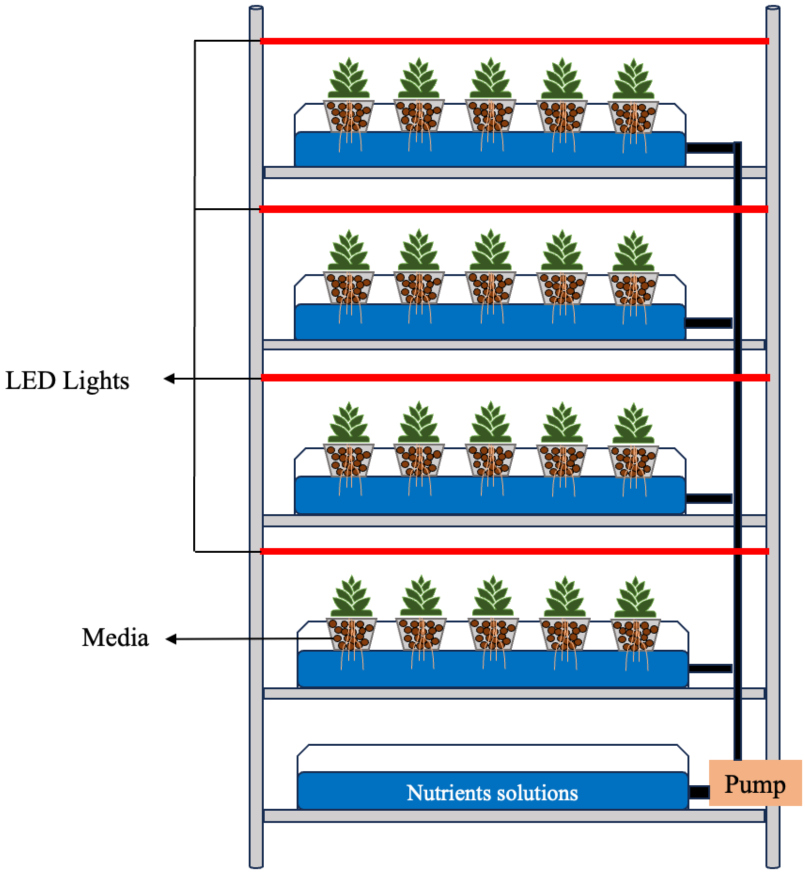

Figure 1. Illustration of the hydroponic system

Table 1. Assigned name of the different parameter

First Cycle	
Parameters	**Assigned name**
3 red 2 blue 1 white	3:2:1
1 red 7 white	0:1:7
2 red 3 white	2:0:3
5 red 1 blue	5:1:0
Second Cycle	
Parameters	**Assigned name**
QGB1 8 W	P8
QGB1 16 W	P16
QGB1 40 W	P40

3. Results and Discussion

In this study, two parameters were varied with the first cycle being different wavelength of LED with fixed power at 9 W. Figure 2 shows the illustration measurement of width and length measured from the leaf.

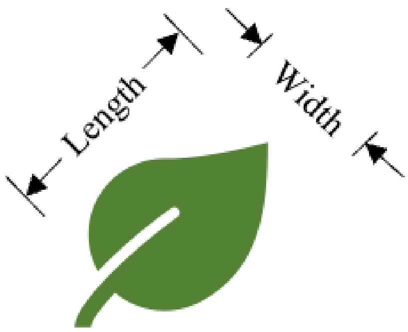

Figure 2. Illustration measurement of length and width of the leaf

The spectrum for each type of LED wavelength variations is shown in Figure 3. All of the LED provides full light spectrum with different intensity that comes from white light wavelength except for 5:1:0 which has the absence of white light.

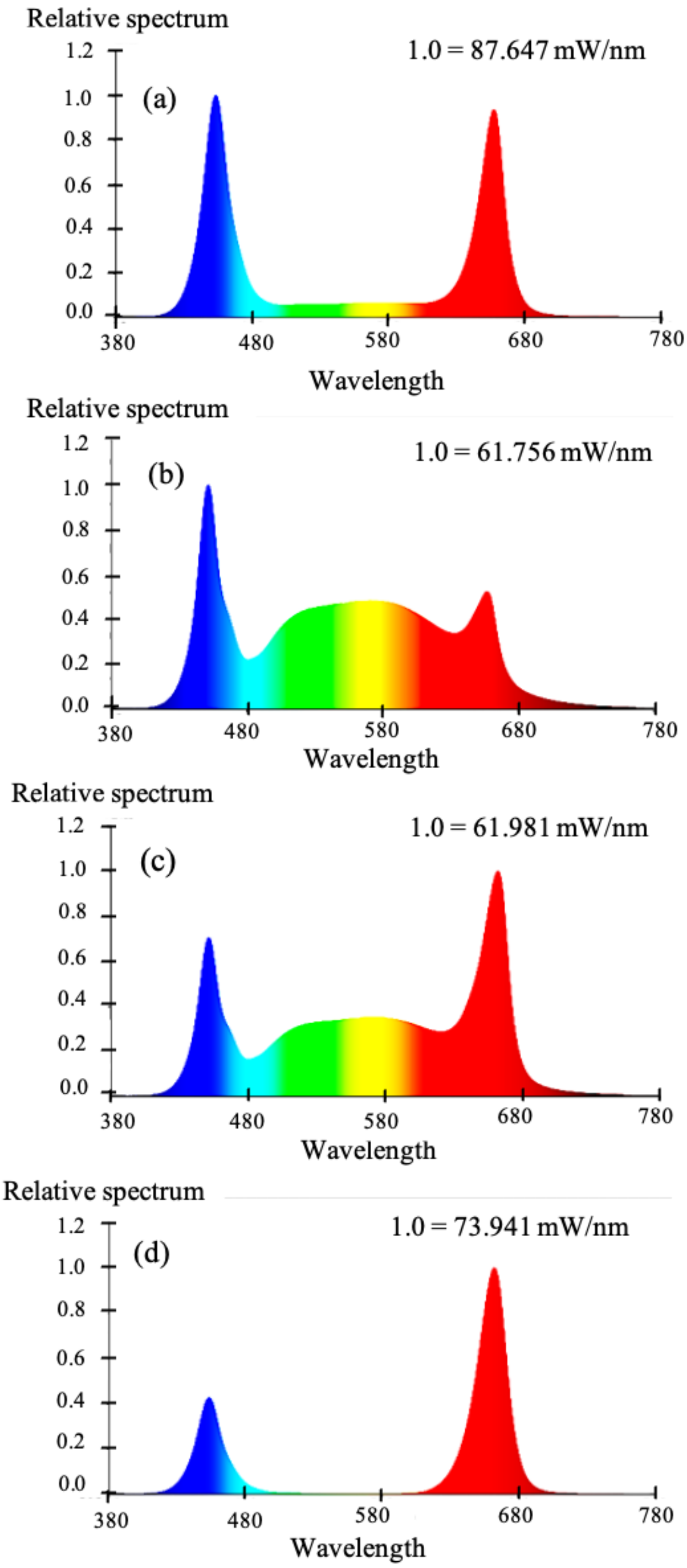

Figure 3. The LED spectrum for (a) 3:2:1, (b) 0:1:7, (c) 2:0:3, and (d) 5:1:0 (Taken from LED datasheet)

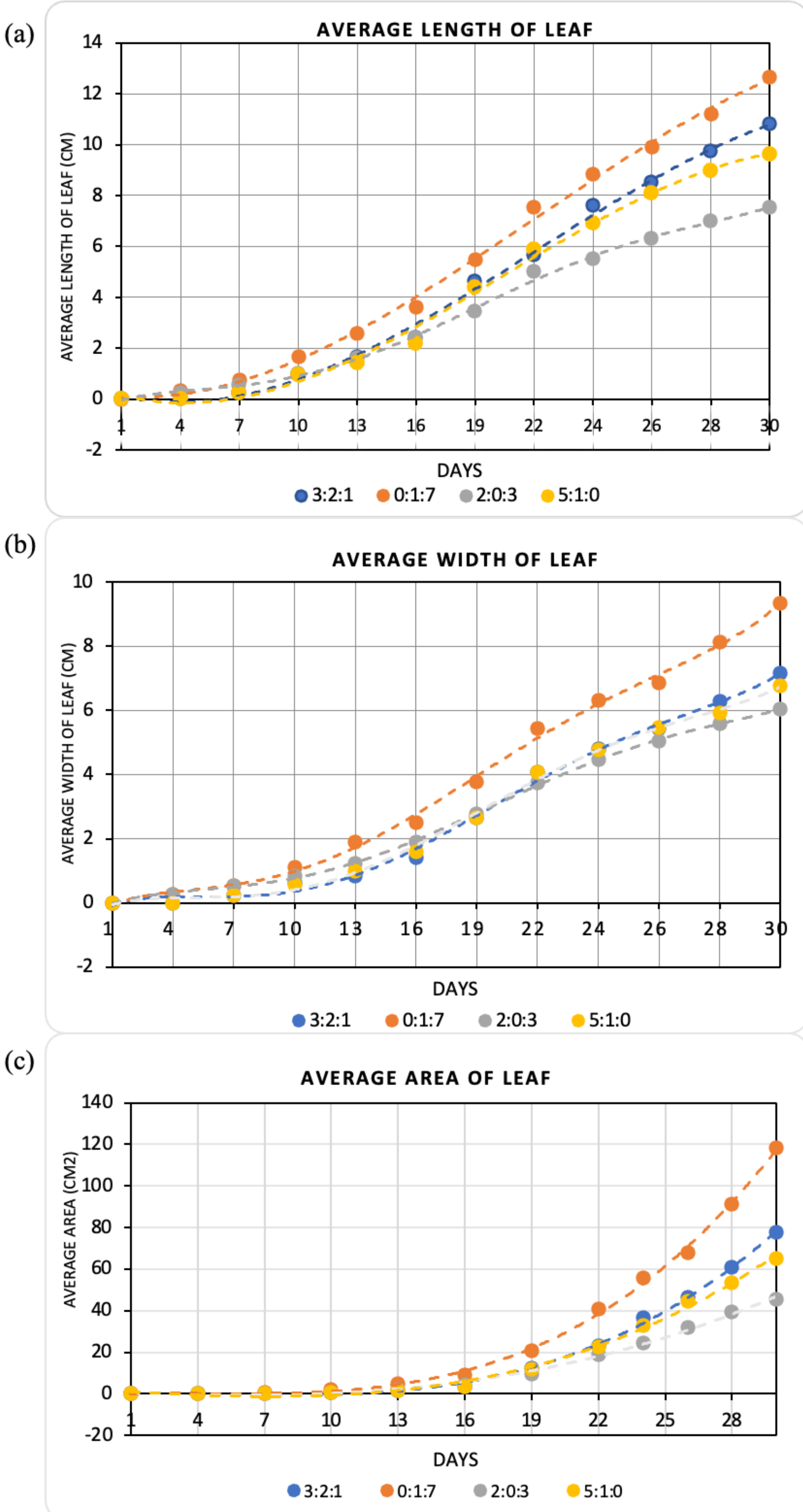

Figure 4. Average (a) length (b) width and (c) area of the leaf after being exposed to different types of LED color light

Figure 4 shows the graph of average length and width of the leaf after being exposed to different wavelengths of LED lights after given times. Three samples of leaves were measured to obtain the average length and width. In Figure 4 (a), there is no increase on length that can be observed on the leaf after day 1. Leaf exposed to 0:1:7 and 2:0:3 started to have an increase after being exposed for 4 days at 0.23 and 0.33 cm, meanwhile no increase can be observed on 3:2:1 and 5:1:0. Starting on day 7, all width of the leaf shows an increase, with 0:1:7 being the constantly highest increase among all the samples with the highest width at 12.70 cm. The same tendency was shown in average width of the leaf as shown in Figure 4 (b). No changes were shown after 1 day of being exposed and all the leaf width started to show an increase after day 4 with 0:1:7 having the highest width at 9.33 cm. The lowest increase of both length and width can be seen on leaf exposed with 2:0:3 at 7.53 and 6.03 cm, respectively.

Figure 5 (a), (b), (c), and (d) shows the growth of the leaf after 26 days by utilizing the hydroponic system described earlier for 3:2:1, 0:1:7, 2:0:3, and 5:1:0, respectively.

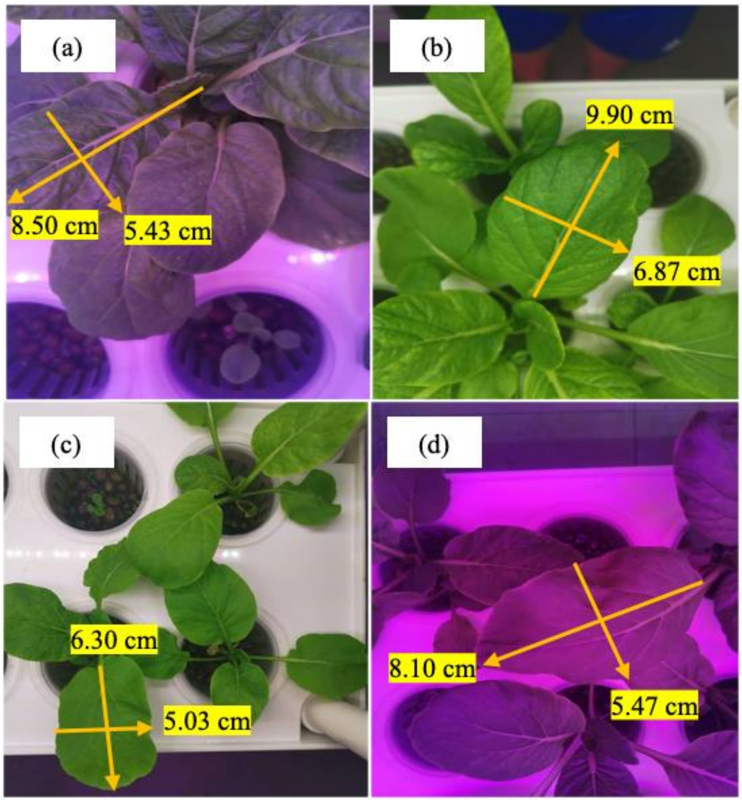

Figure 5. Tatsoi lettuce grown under LED wavelength with a ratio of (a) 3:2:1, (b) 0:1:7, (c) 2:0:3, and (d) 5:1:0

The growth can be divided into two stages which are budding on initial growth as well as stem and leaf development. As mentioned in earlier study, red light wavelength encourages budding and flowering for green plants [15]. Blue lights wavelength plays a role in opening and closing of stomata for carbon dioxide intake and water loss [16], [17]. Meanwhile, white light wavelength provides all wavelength of lights spectrum at lower frequency [18], [19]. For red lights, it plays a big part when a more balance spectrum is given to the plant, for example, assisting white light in encouraging plant growth rather than working independently [15]. This is proven in this study from early budding of 0:1:7 and 2:0:3 first on day 4 followed by 3:2:1 and 5:1:0 on day 7. While 3:2:1 emphasizes more on the use of red light [20], 0:1:7 gives full light wavelength spectrum to the plant in conjunction with slight use of red light to help encourage budding process of the plant. Even with early budding, 2:0:3 gives the slowest growth on both length and width of the leaf as for stem and leaf, the development was promoted by the blue lights. The growth curve of 3:2:1 and 5:1:0 improves significantly during stem and leaf development stages as can be seen in Figure 4 (a) and (b) due to the emphasis of its blue lights. 3:2:1 gives heavy emphasis on blue and red light wavelength which plays an important role in overall development [15], [21]. Meanwhile, 5:1:0 relies entirely on red and blue light with more emphasis on the red light.

In the second cycle, power of the LED grow light was varied to investigate the most efficient power to promote plant growth. The LED used in this cycle was a full spectrum LED light as shown in Figure 6. It covers the whole spectrum of blue, green and red wavelength from 380 to 780 nm. In figure 7, the average length and width of the leaf was shown. Figure 7 (a) shows the length of the leaf started to show an increase after 16 days except for P40 where the growth started on day 13 with 0.30 cm recorded. While P8 and P16 increase steadily, P40 had an exponential increase until day 22 at 3.30 cm before showing steady increase until day 32. For average width of the leaf shown in Figure 7 (b), P40 recorded and early growth at day 13 with 0.13 cm while others started to grow on day 16. All of the leaf shows steady increase with P40 recorded the highest width at 2.37 cm. In the budding phase, higher power provides faster budding time shown by P40 that started budding three days earlier than the lower powered lights. This was also mentioned in the earlier study where higher power intensity gives higher plant length and longest length of the root [22], [23]. As for the stem and leaf development, similar trends can be observed with P40 having faster growth curves [24].

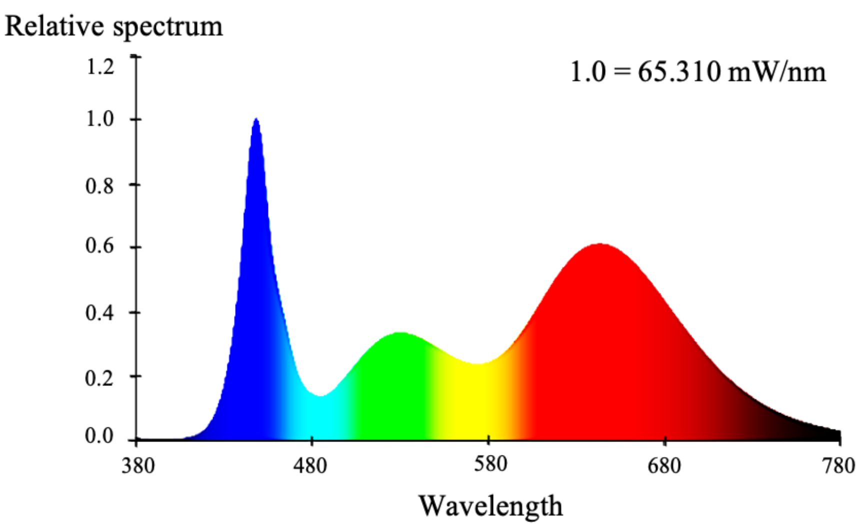

Figure 6. Full spectrum LED lights (Taken from LED datasheet)

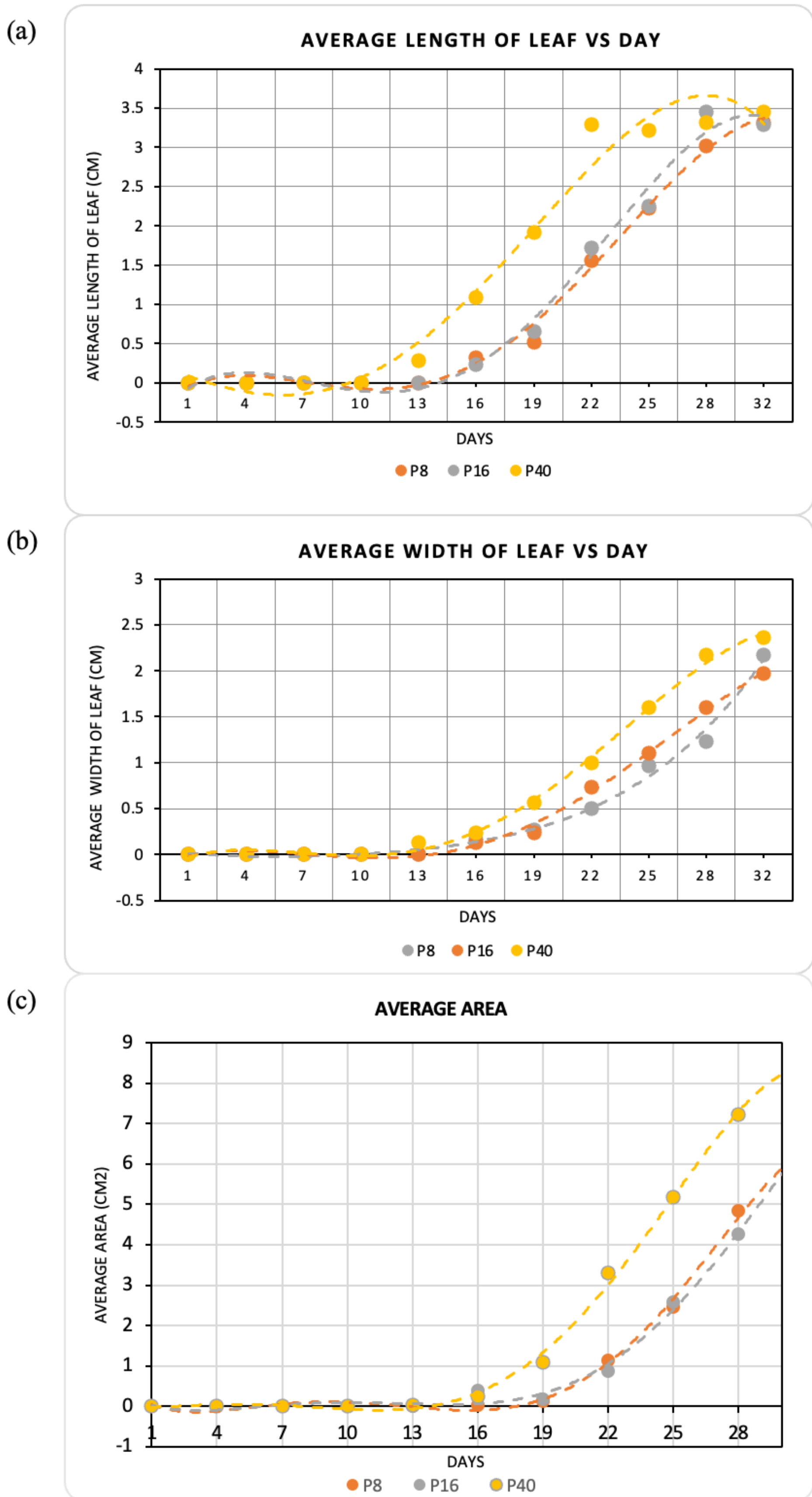

Figure 7. Average (a) length, (b) width and (c) area of the leaf after being exposed to different power of LED grow lights

4. Conclusions

This study shows that the growth of the plants is affected by different LED wavelength and power intensities of the LED. This work adopted commercial LEDs with color variations that consist of different wavelengths. The 7 white 1 red LED shows the highest average length and width after 30 days. With the help of red lights wavelength, budding process were promoted to have an early start compared to other color. Meanwhiles, having white LED lights gives a full color spectrum wavelength which includes blue light that encouraged stem and leaf development. In the second cycle with different light power intensity, having high power will mainly promote the budding process. With all spectrum color presence, the stem and leaf development of the plants was help by high power of the LED. The adoption of commercial LED lights in this work contributes to the direct benefits of indoor vegetable farmers and helps to optimize the growth of the plants and improve the overall farming yield.

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