Vol. 13, No. 4 (2024): 1249 – 1261 http://dx.doi.org/10.23960/jtep-l.v13i4.1249-1261

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Artificial Lighting System Design with PWM Control for the Growth of Kangkung Microgreen

Muhammad Fauzan[1], Syukriyadin[1], Fahri Helta[1], Syahrizal[1,✉], Alfisyahrin[1]

[1] Department of Electrical and Computer Engineering, Faculty of Engineering, Syiah Kuala University, Banda Aceh, INDONESIA

Article History:

Received : 07 May 2024
Revised : 16 July 2024
Accepted : 22 July 2024

Keywords:

Artificial lighting,
Indoor farming,
Kangkung,
Microgreen,
Pulse wave modulation.

Corresponding Author:
✉ syukriyadin@usk.ac.id
(Syukriyadin)

ABSTRACT

Microgreen plants such as lettuce, spinach, and kangkung can be cultivated indoors, with artificial lighting like Light Emitting Diodes (LEDs) replacing sunlight. This study compared the growth of kangkung microgreens under artificial lighting using Pulse Width Modulation (PWM) versus without PWM. Two sample trays, each containing 50 grams of kangkung seeds, were placed 50 cm below the light. The first tray used PWM lighting, starting with a 65% duty cycle at 8 a.m, increasing to 100% by 12 p.m, and decreasing back to 65% by 4 p.m. The second tray received constant lighting without PWM. Results showed that PWM improved power efficiency from 16.3 W without PWM to 13.36 W with PWM. Growth of kangkung microgreens improved with PWM, evidenced by better stem length, leaf count, wet weight, stem diameter, petiole length, and leaf width, although single root length with PWM (9.68 cm) was slightly shorter than without PWM (9.98 cm).Base on statistical t-test results showed that there was a significant difference in stem length between lighting treatments using the PWM method and without using the PWM method, with a significance level of 5%. The study successfully developed an automated lighting control system using PWM that enhances plant growth.

1. INTRODUCTION

Vertical farming is an agricultural concept that does not require soil media but can be replaced with air (aeroponics), water (hydroponics), or other substrate media that has nutrients like soil. Basically, indoor farming facilities consist of several component units, building structures covered with thermal insulation, multi-racks equipped with lighting, cooling systems, fan-based air circulation, CO^2 supply for plant photosynthesis processes, nutrient supply with water pumps, and environmental control units (Avgoustaki & Xydis, 2020). In its application, vertical farming can be done indoors, outdoors, and also a combination of both (hybrid).

The difference among these three systems is in the light source used. Sunlight is used in outdoor farming systems as the sole light source, while indoor farming systems use lamps as a substitute for sunlight. And the hybrid farming system uses a combination of both light sources. Sunlight is used as the main light source and lamps are used as additional light to support plant growth for the better. The lights used are adjusted to the type of plant. Lights can be Light Emitting Diode (LED), incandescent, or fluorescent types (Sena *et al*., 2024).

During growth, lighting cannot be separated from plants. Light is one of the most important environmental factors affecting plant growth, not only as the driving force of photosynthesis but also as an important regulator of plant growth and development (Tang *et al*., 2022). Blue light can affect leaf growth, red light increases flowering and fertility, while green light is mostly reflected so it does not greatly affect the photosynthesis process (Runkle, 2017).

The sun has a lighting cycle, which is bright during the day and dim in the afternoon (Shishegar & Boubekri, 2016). By using lamps as a light source, the light intensity received by plants will be constant, in contrast to the sun-based lighting cycle. This can make plant growth not optimal, such as the length of leaf growth and reduced plant weight. Gradually increasing the light intensity can enhance the dry weight of the plant (Jin *et al*., 2023). Thus, a control circuit is needed to control the light intensity, so that it follows the solar lighting cycle. One of the control circuits used is PWM based.

Pulse Width Modulation (PWM) is a control method that uses the difference between active and inactive waves in a wave period as a percentage, called the duty cycle (Lubis & Yanie, 2022). PWM can be generated with an Arduino and a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) driver to control lamp light intensity. MOSFET is a type of transistor used widely in electronic devices for switching and amplifying signals. To control the on/off switching process of a MOSFET, a modulated signal with a specific frequency from a source is required to be fed into the MOSFET. The duration of the on/off switching of the MOSFET depends on the pulse width of the PWM signal, which is regulated according to the duty cycle. A MOSFET is needed as it efficiently handles the higher currents and voltages required by LED lamps, allowing precise regulation of light intensity. This leads to better energy efficiency and optimal conditions for plant growth.

Kangkung microgreen, is used in this study due to its short growth cycle, high nutritional value, and functional properties. Microgreens are richer in antioxidants, phenolics, vitamins, and minerals compared to their mature counterparts, and they have health-promoting properties, making them highly valued as "functional foods" (Tamilselvi, 2018). They add unique textures and flavors to meals and are a rich source of antioxidants and phytonutrients, which can lower the risk of certain cancers and heart diseases (Xiao *et al*., 2012).

Indoor farming, also known as vertical farming, uses methods like aeroponics, hydroponics, or nutrient-rich substrates instead of soil. Lighting systems can be artificial (using lamps), natural (using sunlight), or hybrid (using both) (Avgoustaki & Xydis, 2020). The key components include a closed building, plant growth system, artificial lighting, nutrient supply, air conditioning, CO^2 supply, and environmental control (Al-Kodmany, 2018).

One of the most important things for plant growth and development is light, which is a source of energy for plants to photosynthesis. Blue and red light are more efficient in driving photosynthesis on the upper side of the leaf, where they are absorbed by the chlorophyll a and b pigments (Liu & van Iersel, 2021). Meanwhile, green light penetrates deeper into the leaf and drives carbon fixation in the deeper layers of the leaf by the plant pigment (carotenoid) β-carotene, in addition to the photosynthesis process. The rate of photosynthesis is the accumulation of the absorption process of the three pigments, chlorophyll a and b and β-carotene (Neo *et al*., 2022).

Kangkung Microgreen

Ipomoea reptans Poir (locally known as kangkung) can be grown and harvested within 7 to 14 days after planting. It is called microgreen. Kangkung, which is still in this microgreen stage, is usually harvested before the appearance of real leaves but already has a perfect first leaf (As'adiya & Murwani, 2021).

The process of growing kangkung microgreen is generally done in sterile media such as rockwool or organic media such as cocopeat (Treadwell *et al*., 2020). Sterile growing media helps to ensure a clean growth environment that is free from pathogens that can harm the plant. Humidity of 40 - 60% and temperature of 24 - 27 ^{o}C are optimal for microgreen (Tamilselvi & Arumugam, 2018). Sufficient lighting is needed for kangkung microgreen to grow well, at least, the light intensity of the lamp is between 2000 - 4000 Lux (Siminovitch, 2014). Additional fertilizers are not used because microgreen relies on the nutrients already contained in the seeds when germinating, so the growth process is simpler compared to the cultivation of mature vegetables (Asri, 2020).

In this research, a study was conducted through a PWM control circuit to regulate the intensity of light in artificial lighting in indoor agriculture, specifically for kangkung microgreen. By implementing PWM control, it is expected to create optimal lighting conditions according to the needs of plants and can save energy use in indoor agriculture. This arrangement is expected to reduce potential growth disorders, such as the length of leaf growth and reduced plant weight (Jin *et al*., 2023), which occur due to differences in lighting cycles with sunlight.

2. MATERIALS AND METHODS

2.1. Materials and Tools

This study used primary data on the growth and development of kangkung microgreen for 10 days, namely from day 1 to 10 day after planting (DAP). Measurement variables include branch length, petiole length, leaf length, leaf width, branch diameter, root length, number of leaves and plant weight. In this research, an indoor farming system with a light intensity regulator with the PWM method is used, Table 1 is a list of tool names and their uses:

Table 1. Research tools

No.	Tools	Justification of Use
1	Cable	Electrical Conductors
2	Insulation	Conductor Insulation
3	AM2301 Temperature and Humidity Sensor	Temperature & Humidity Sensor
4	Light Intensity Sensor BH1750	Light Intensity Sensors
5	INA219 Current and Voltage Sensor	Current and Voltage Sensors
6	DS3231 Real Time Clock Module	Data Logger Timer
7	Micro SD Card Reader Module	Storage Card Reader
8	Micro SD Card	Data Logger Storage
9	MOSFET IRF540N	PWM Driver
10	Arduino Mega 2560 R3	Microcontroller
11	Oscilloscope	Signal Observer
12	Iron Ruler	Root and Leaf Measurement Tool
13	Vernier Caliper	Branch Measuring Device
14	VRLA GEL Deep Cycle 65 Ah 12 V Battery	DC Power Storage
15	LED T5 lamp 6500 K 10 W	Lighting
16	Iron and Hole Elbow Plate	Plant Rack Frame
17	Wooden Board	Plant Shelf Wall
18	Iron Plate	Plant Shelf Ambiance
19	Plastic Tray	Planting Media Container
20	Bolt and Ring	Mechanical Fastening

The MOSFET IRF540N was selected as a PWM driver for LED intensity control due to its low threshold voltage (4V) and compatibility with 5 V microcontrollers like the Arduino Mega 2560 R3. The Arduino Mega 2560 R3 was chosen for its ample flash memory (256 Kb) and numerous pins (54 Digital, 15 PWM, 16 Analog). A 6500 K 10 W LED T5 lamp was used for its compact size, energy efficiency, and suitable color temperature for microgreens. Measurements were taken using a Vernier caliper, ruler, and digital scales. Voltage and current data loggers measured electrical consumption. The research was conducted from September to December 2023 at the Electric Power Conversion Laboratory, Department of Electrical and Computer Engineering, Syiah Kuala University, Banda Aceh.

2.2. Research Flowchart

To achieve the objectives in this study, several stages of research were carried out as shown in Figure 1.

2.3. Designing an Artificial Lighting System

The construction of the indoor farm was made as shown in Figure 2 using a 6500 K 10W LED T5 lamp placed at a distance of 50 cm from the plant sample. This construction is built with an angle plate hole for the framework, and wooden boards as walls and plant placement. The PWM control circuit uses an Arduino Mega 2560 R3 microcontroller equipped with a data logger, light intensity sensor, temperature and humidity sensor, voltage and current sensor as shown in Figure 3.

MOSFET IRF540N is also used to control the light intensity of the lamp which uses 12 V voltage from the battery. This circuit will adjust the light intensity of the 6500K LED T5 lamp to set the duty cycle to 65% at 08.00 AM, then increase to 100% at 12.00 PM, and back down to 65% at 16.00 PM. Then the library and constant variables required

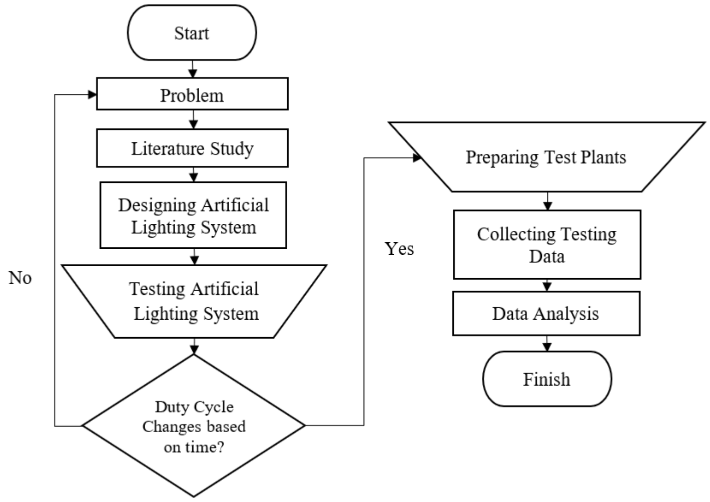

Figure 1. Research flowchart

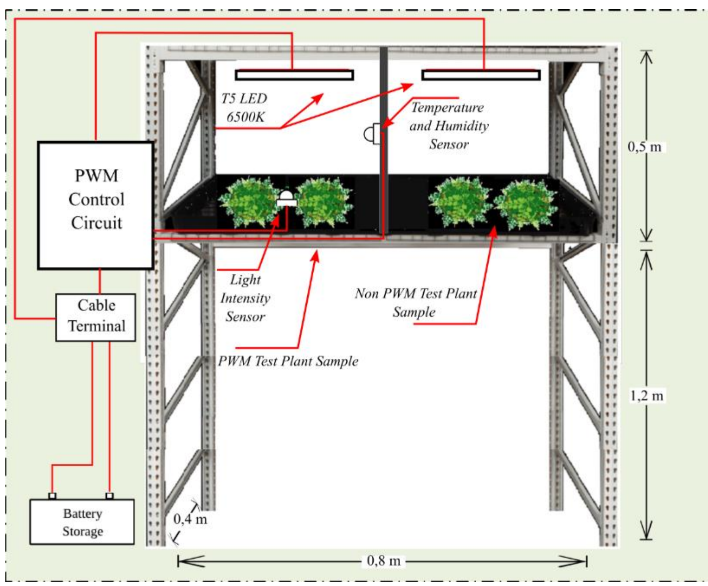

Figure 2. Indoor farm construction model

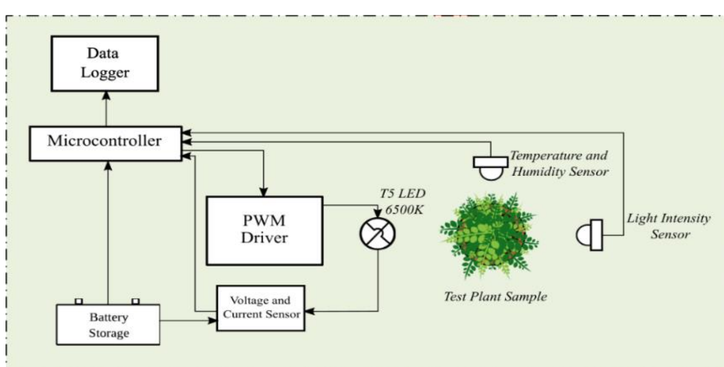

Figure 3. PWM control circuit design

for duty cycle control will be determined. To set the duty cycle on the Arduino, the TimerOne library is used (Dimitrov *et al*, 2024). The function used to set the duty cycle is the map function, which can set the duty cycle level based on the time value in the RTC module. After the program is complete, the PWM output pin will be connected to the Gate MOSFET leg which functions to regulate the flow of current between the Source and Drain terminals (Balogh, 2017).

The results of the design will be built so that a prototype of an artificial lighting system with PWM control is produced. The prototype will control the light intensity of the lamp by adjusting the duty cycle. The prototype will also produce data loggers of the system environment (humidity, temperature, and light intensity) and system electrical conditions (voltage and current).

2.4. Testing the Artificial Lighting System

The system that has been built needs to be tested for functionality to match the specifications required in this research. Some of the tests carried out include testing the duty cycle and the resulting PWM signal. The duty cycle is tested by observing the duty cycle changes in the resulting data logger. This test aims to determine whether the program to increase and decrease the duty cycle used is correct. Then testing is done with an oscilloscope to see the resulting PWM signal. This test aims to determine whether the PWM signal generated by Arduino is in accordance with the desired specifications.

2.5. Preparing Test Plants

Two coco peat planting mediums used to cultivate kangkung microgreen seeds were placed in trays (33 cm x 24 cm x 5 cm), as shown in Figure 4 (a). One tray each for PWM and non PWM lighting. Kangkung microgreen seeds were used and sown for 2 days as shown in Figure 4 (b) as experimental plants without any lighting. The seedlings used were 50 grams/trays spread on cocopeat growing media in two plastic trays. Illumination was carried out with T5 LED lights for 8 hours from 08.00 AM to 04.15 PM for 10 days. Air conditioner was used to maintain room temperature of 24-27°C and humidity of 40%-60%.

(a) (b)

Figure 4. Planting Kangkung microgreen: (a) Cocopeat media, and (b) Kangkung microgreen seedlings at 2 DAS.

2.6. Collecting Testing Data

The kangkung microgreen plants in the tray had a uniform population. The degree of homogeneity within a population of kangkung microgreen plants can be evaluated by examining observable traits that indicate the level of uniformity and consistency within the population. Plant height, leaf color, number of leaves, leaf shape, and growth rate are essential aspects that can be studied to assess the homogeneity of microgreen populations (Syukriyadin *et al*., 2024). Based on prior study carried out by (Dimita *et al*., 2022), homogeneity microgreen plant samples were obtained from 1-2 plants for the 4-week period; therefore, in this investigation, measurements were performed using 3 random samples of each treatment to be evaluated daily and continued for ten days. Microgreen growth data was taken at

04.15 p.m for 10 days after planting (DAP) which began after the sown kangkung microgreen was placed on the plant rack. A vernier caliper was used for branch diameter, a crossbar for branch length, petiole length, leaf area, root length, and a digital scale for plant weight. Light intensity, temperature, humidity, voltage and current read by the sensors will be recorded on the data logger.

2.7. Data Analysis

The data obtained is in the form of daily average data. To analyze the performance of PWM control-based artificial lighting, a comparison of plant growth and development data, including branch length, petiole length, leaf area, branch diameter, root length, number of leaves, plant weight, and electrical power consumption, between the PWM control system and the system without PWM control is carried out. Additionally, the t- test is used to determine the significant differences between the two systems for each growth parameter.

3. RESULTS AND DISCUSSION

3.1. System Design

The resulting controller circuit can be seen in Figure 5. Used to control 2 T5 LED lamps 10 W. The control carried out is on the PWM duty cycle to control the light intensity of the lamp. Arduino Mega is used to control the PWM signal and generate data loggers from voltage, current, humidity, temperature, and light intensity sensors. Using a 12 V battery electric energy source, the signal generated by the Arduino is a 5 V PWM signal. So that a MOSFET is needed to control the T5 LED lamp with a voltage of 12 V.

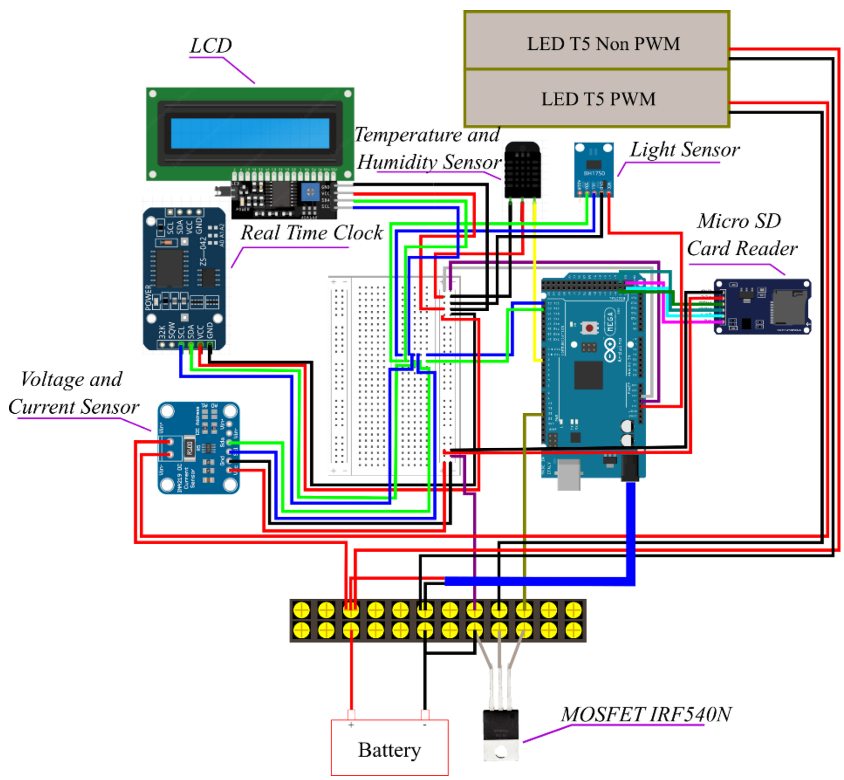

Figure 5. Light intensity control circuit

Several libraries and constant variables are used in the program, as shown in Figure 6. Library 'TimerOne.h' is used to set the PWM duty cycle on the LED pin ('LEDPin'). The variables 'startPWM' and 'endPWM' determine the start and end values of the PWM duty cycle, while 'fadeDuration' and 'endfadeDuration' determine the first and second periodic time duration for the duty cycle change. The first duty cycle change occurs from 08.00 AM to 12.00 PM or ends at the first 4 h of system power on, so ‘fadeDuration’ is set to 14,400,000 ms (4 h). While the second duty cycle change occurs at 12.00 to 04.00 PM or ends after 8 h of the system being turned on, so the ‘endfadeDuration’ is set to 28,800,000 ms (8 h). The variables ‘waktu’, ‘sekarang’, and ‘startFade’ are used to track time in milliseconds and calculate the time difference between the current loop iteration and the previous loop iteration.

```
#include <TimerOne.h>
const int LEDPin = 12;
float pwmL = 0;
int startPWM = 65;
int endPWM = 100;
unsigned long waktu = 0;
unsigned long sekarang = 0;
unsigned long startFade = 0;
const unsigned long fadeDuration = 14400000;
const unsigned long endfadeDuration = 28800000;
```

Figure 6. Library and constant variables of duty cycle control program

```
void loop() {
 waktu = millis();
 uptime = ((waktu/1000)/60);
 sekarang = waktu - startFade;
  if (sekarang <= fadeDuration) {
    pwmL = map(sekarang, 0, fadeDuration, startPWM, endPWM);
    Timer1.pwm(LEDPin, (pwmL / 100) * 1023);
...
```

Figure 7. Duty cycle control program first part

```
...
  } else if (sekarang <= endfadeDuration) {
    pwmL = map(sekarang - fadeDuration, 0, fadeDuration, endPWM, startPWM);
    Timer1.pwm(LEDPin, (pwmL / 100) * 1023);
...
```

Figure 8. Duty cycle control program second part

The duty cycle control of the PWM signal uses the map function. The control program can also be divided into two parts, namely during duty cycle increase and decrease. In the first part as shown in Figure 7, the program uses the `map()` function to map the elapsed time (`sekarang`) into the range of values between `startPWM` and `endPWM`, which is then used to set the PWM duty cycle through the `Timer1.pwm()` function. This duty cycle value is expressed as a percentage of the PWM value (from 0 to 1023), and the setting is repeated every loop iteration.

As in Figure 8, the program again uses the `map()` function to derive the duty cycle, this time to map the remaining time calculated from the first phase (`sekarang - count_milis`) into the range of values between `endPWM` and `startPWM`. This calculated duty cycle value is then used to reset the PWM duty cycle through the `Timer1.pwm()` function. As in the first phase, the duty cycle value is expressed as a percentage of the PWM value and is repeated every loop iteration. Thus, controlling the PWM duty cycle occurs dynamically depending on the elapsed time, creating the desired fading effect on the LED connected to the PWM pin.

3.2. Testing the System

Duty cycle testing is done by observing the duty cycle changes in the data logger generated by Arduino. So that the system duty cycle changes per day are obtained as in Figure 9, with a duty cycle percentage change of 1% every 6 min

40 s. Duty cycle percentage was gradually increased from 65% to 100% at the first 4 h. Then it drops back gradually to 65% at the second 4 h.

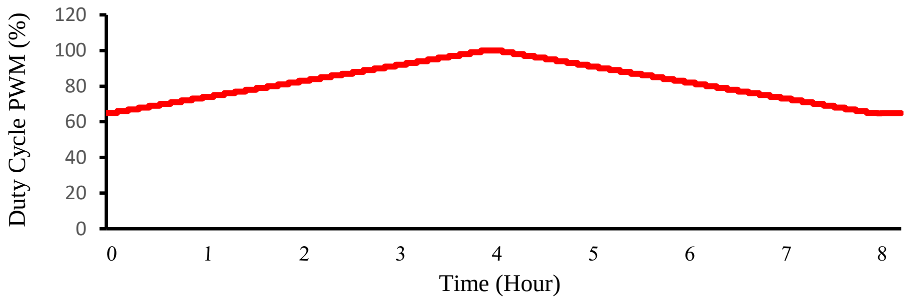

Figure 9. Duty cycle controller circuit results

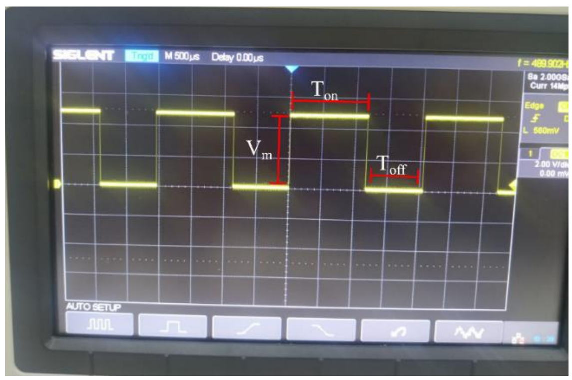

Figure 10. PWM signal on gate MOSFET when duty cycle 65%

Testing the PWM signal from the Arduino using an oscilloscope. The lamp voltage in this study is regulated using PWM. PWM provides a box signal that has the same voltage, but the pulse width is changed in percent duty cycle, as in Figure 10. The oscilloscope settings are 500 µs/div on the horizontal axis and 2V/div on the vertical axis. The oscilloscope is connected to the Gate MOSFET. Vm 2.5 div is obtained, so 2.5 x 2 = 5 V. Ton 2.2 div, so 2.2 x 500 µs = 1.3 ms. Toff 1.8 div, so 1.8 x 500 µs = 0.7 ms. Until the duty cycle D = (1.3/(1.3+0.7)) x 100% = 65%. Then, to get the voltage on the PWM controlled lamp (VPWM) then can use the effective voltage formula (VRMS).

If we look at the voltage on the lamp controlled with PWM with a duty cycle of 65%. A signal is obtained as shown in Figure 11. By changing the 5V/div setting on the vertical axis, the maximum voltage of the signal is 2.4 x 5 Vm = 12 V. The voltage on the lamp is the voltage from the battery that has been modulated with PWM through the MOSFET. However, the resulting signal is not a perfect square signal. This is caused by noise in the load (LED lamp) and the control circuit used.

3.3. LED Lighting Analysis

The change in voltage follows the change in PWM duty cycle with the equation y = 0.0003x + 10.255 with R^2 = 0.9323, as shown in Figure 12. This is because the duty cycle determines how long the PWM signal is in the "on" state or provides voltage, so the higher the duty cycle, the greater the average effective voltage provided to the associated device. The power on the PWM lamp drops in the morning and evening. This follows the change in PWM duty cycle at that hour. Based on Figure 13, at start and end of the PWM duty cycle is at 65%, the power is at 10.6 W. At 4 hour mark, the PWM duty cycle is at 100%, the power is at 16.3 W. This proves that the power is proportional to the PWM duty cycle. The non-PWM lamp power is stable at 16.3 W, but the PWM lamp power is lower at average of 13.36 W.

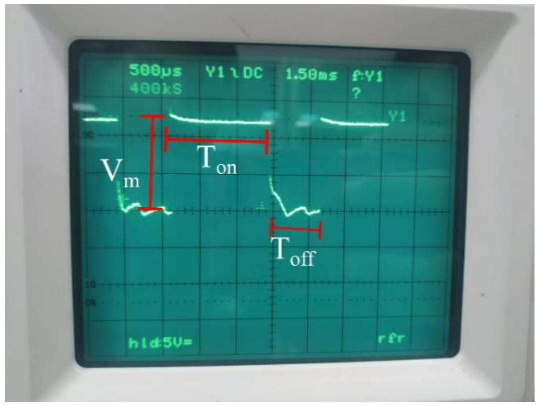

Figure 11. PWM Signal on T5 LED Lamp when Duty Cycle 65%

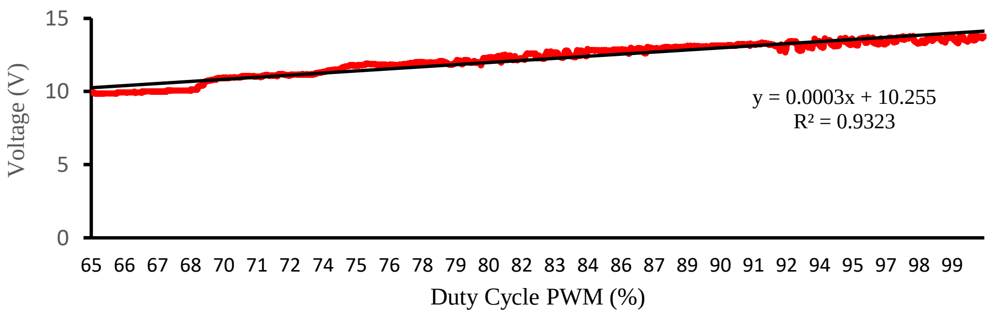

Figure 12. Graph of average voltage 1-10 DAP against duty cycle

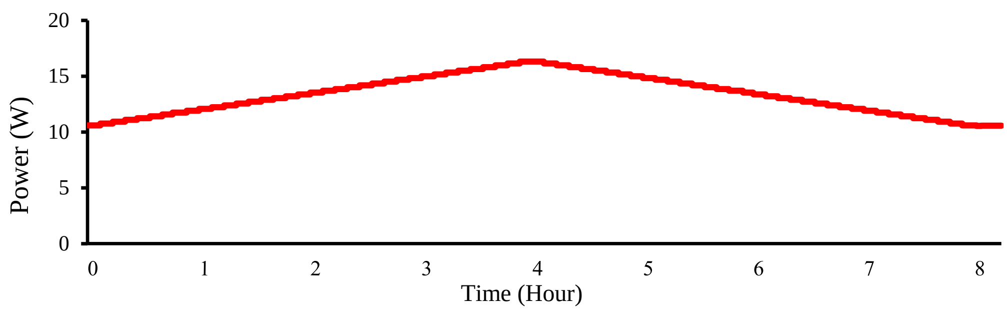

Figure 13. Graph of average power against time during 1-10 DAP

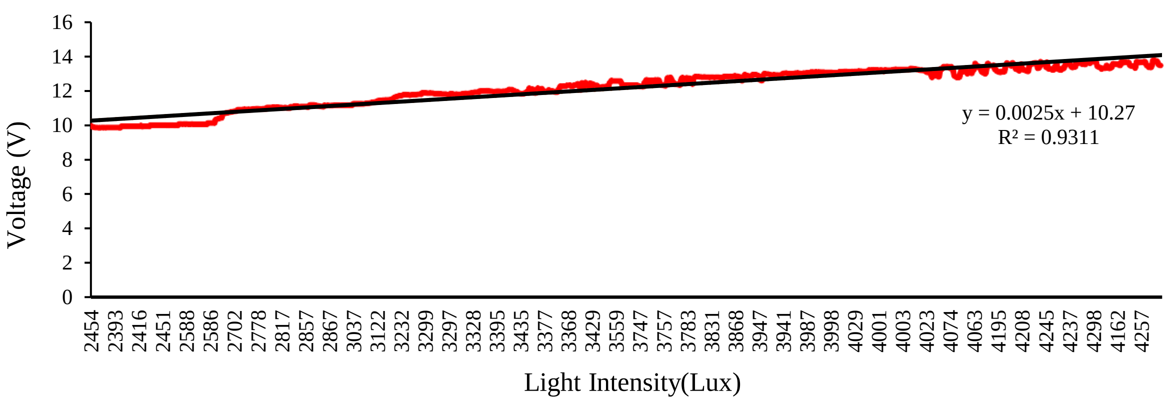

Figure 14. Voltage Graph against Average Light Intensity 1-10 DAP

Based on Figure 14, the lowest lamp light intensity is 2391 Lux when the voltage is 9.86 V and the highest is 4330 Lux when the voltage is 13.5 V. High voltage produces high light intensity. The relationship between voltage and light intensity can be defined by the equation $y = 0.0025x + 10.27$ with $R^2 = 0.9311$.

Figure 15 illustrates the comparison of the light produced by changing each duty cycle, showing that higher duty cycles result in greater light intensities. The lowest recorded intensity is 1882 Lux at a 65% duty cycle, while the highest is 4330 Lux at a 100% duty cycle. This relationship is quantitatively defined by the linear equation ($y = 0.0231x + 64.487$) with a coefficient of determination ($R^2 = 0.9992$), indicating an almost perfect linear correlation between the duty cycle and light intensity. Thus, as the duty cycle increases, the light intensity also proportionally increases.

3.4. Environmental Data Analysis

Humidity and temperature settings on the system, set based on optimal conditions for the growth of kangkung microgreen. The parameters used are ±25ºC for temperature, and 40% - 60% for humidity (RH) (Jin *et al*., 2023). Based on Figure 16, the humidity condition in the system in the morning (first 4 h) is 70%. And decreased to 55% at 1 and half hour mark and stabilized until 8 h mark.

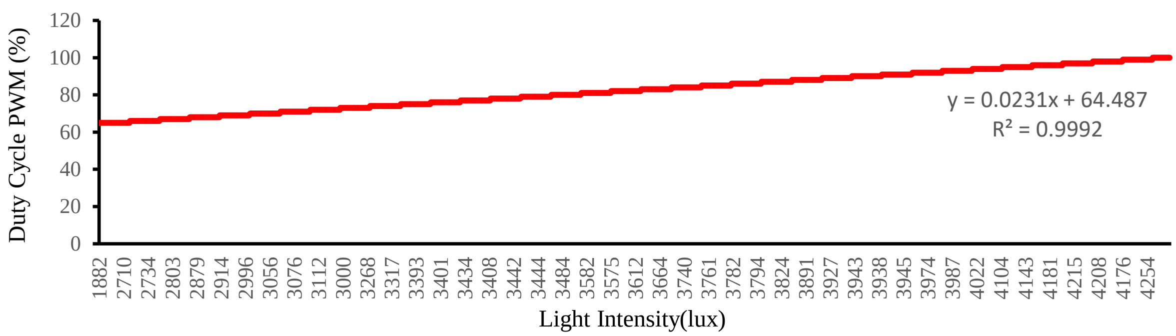

Figure 15. Duty cycle graph against average light intensity 1-10 DAP

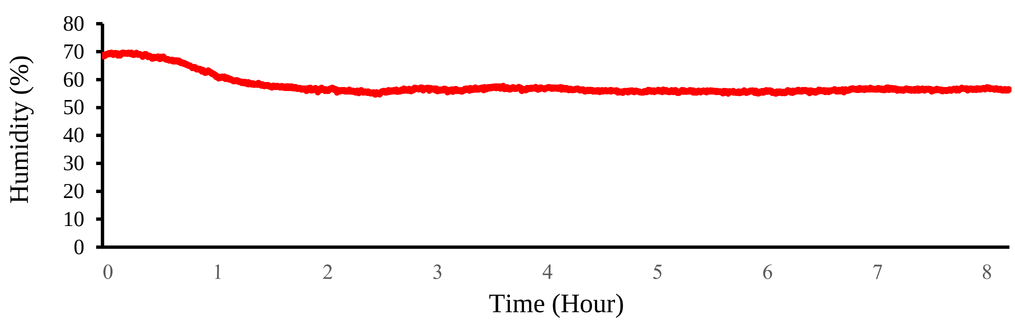

Figure 16. Graph of average humidity 1-10 DAP

Based on Figure 17, the average temperature in the system is 24ºC. The highest temperature occurs in the morning (first 4 h) which is 26ºC, which decreases until it stabilizes at 24ºC at 2 h mark.

The environmental conditions supported the growth of kangkung microgreen by meeting specified parameters. Temperature and humidity increased in the morning due to the lack of temperature control following the system turned off after 8 h, but normalized with the morning activation of air conditioning. Light intensity was maintained between 2000-4000 Lux, optimal for plant growth (Lubis & Yanie, 2022). According to Figure 18, the T5 LED lamp's average light intensity rose from 2454 Lux to 3705 Lux initially, stabilized at 2180 Lux by the 2-h mark, peaked at 4330 Lux by 4 h, and decreased to 2960 Lux by 8 h. The lamp without PWM control had an average intensity of 3500 Lux.

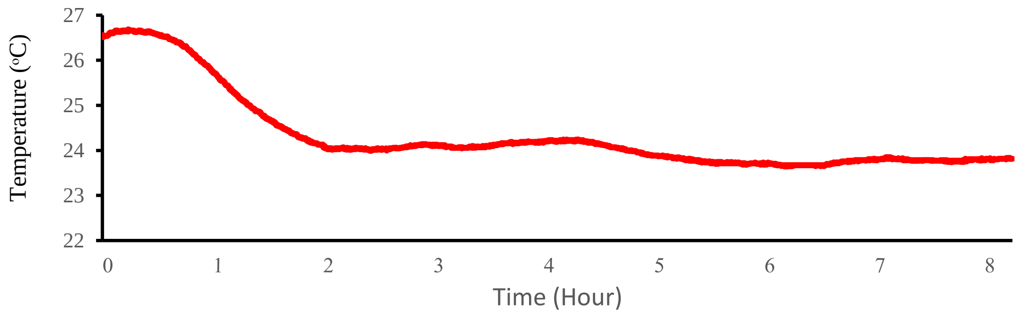

Figure 17. Average temperature chart 1-10 DAP

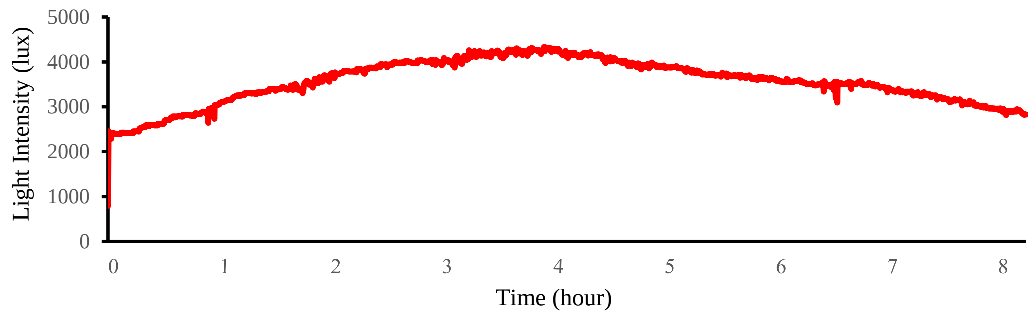

Figure 18. Graph of average light intensity 1-10 DAP

3.5. Plant Growth and Development Analysis

The measurement samples of kangkung microgreen from can be seen in Figure 19. Three samples randomly taken each tray every afternoon after the system shuts down. Kangkung microgreens using PWM have shown better results in several growth parameters: wet weight (0.46 g), stem diameter (1.78 mm), petiole length (3.09 cm), number of leaves (4.4 strands), stem length (8.11 cm), single root length (9.68 cm), leaf length (2.82 cm) and leaf width (7.10 mm). In contrast, the non-PWM sample showed better root length with a measurement of 9.98 cm. Overall, kangkung microgreens using PWM control demonstrated superior growth performance. However, to ensure a significant difference a statistical t-test was required, and the results are as shown in Table 2.

Figure 19. PWM and non PWM microgreen kangkung measurement samples

Table 2. Differences in average kangkung microgreen growth 1-10 DAP based on statistical *t*-test

Measure Variables	Light Treatment	
	PWM	Non PWM
Wet weight (g)	0.46a	0.42a
Stem diameter (mm)	1.78a	1.77a
Petiole length (cm)	3.09a	3.02a
Number of leaves (strands)	4.40a	4.10a
Stem length (cm)	8.11a	7.48b
Single root length (cm)	9.68a	9.98a
Leaf length (cm)	2.82a	2.95a
Leaf width (mm)	7.10a	6.83a

Note: Numbers followed by the same letter at the same row indicate not significantly different in the *t*-test analysis, with a significance level of 5%.

Based on the statistical t-test, as shown in Table 2, the PWM lighting treatment on the test samples shows real differences in stem length parameters using PWM lighting with a significance level of 5%. Apart from these parameters, there are no real differences between the parameters measured, with a significance level of 5%.

4. CONCLUSIONS

This research successfully developed an automatic artificial lighting control system using PWM for kangkung microgreen plants, enhancing growth while reducing power consumption. The non-PWM lamp power remained stable at 16.3 W, while the PWM lamp averaged 13.36 W. Comparison of measurement parameters, namely stem length, leaf width, number of leaves, petiole length, stem diameter, and wet weight of kangkung microgreen plant samples illuminated with the PWM method, has a more excellent average value of measurement. However, the average value of measurement of single root length and leaf length of kangkung microgreen plants illuminated with constant light is more extended. Based on the data analysis of the two sample treatments using the statistical t-test shows that the two samples are not significantly different at the 5% significance level for the parameters of wet weight, leaf width, stem diameter, petiole length, number of leaves, single root length, leaves length, and with leaves of the samples. However, for the stem length, the two sample treatments are significantly different at the 5% significance level. This difference means that the kangkung microgreen using artificial lighting with the PWM method has a faster growth and development process.

ACKNOWLEDGEMENT

The authors would like to thank the laboratory of Electric Power Conversion, Department of Electrical and Computer Engineering, Faculty of Engineering, Syiah Kuala University for providing us place to conducting our research.

REFERENCES

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, ***8***(2), 24. https://doi.org/10.3390/buildings8020024

As'adiya, L., & Murwani, I. (2021). Pengaruh lama penyinaran lampu led merah, biru, kuning terhadap pertumbuhan microgreen kangkung (*Ipomoea reptant*). *Folium : Jurnal Ilmu Pertanian*, ***5***(1), 14. https://doi.org/10.33474/folium.v5i1.10358

Avgoustaki, D.D., & Xydis, G. (2020). Chapter one - How energy innovation in indoor vertical farming can improve food security, sustainability, and food safety? *Advances in Food Security and Sustainability*, ***5***, 1–51. https://doi.org/10.1016/bs.af2s.2020.08.002

Balogh, L. (2017). Fundamentals of mosfet and igbt gate driver circuits application report. *Texas Instruments*, 1–48.

Bhaswant, M., Shanmugam, D.K., Miyazawa, T., Abe, C., & Miyazawa, T. (2023). Microgreens – A comprehensive review of bioactive molecules and health benefits. *Molecules*, ***28***(2), 867. https://doi.org/10.3390/molecules28020867

Dimita, R., Min Allah, S., Luvisi, A., Greco, D., De Bellis, L., Accogli, R., Mininni, C., & Negro, C. (2022). Volatile compounds and total phenolic content of perilla frutescens at microgreens and mature stages. *Horticulturae*, ***8***(1). https://doi.org/10.3390/horticulturae8010071

Dimitrov, S., Tane, J.,Despatis, J., Polli, M., Clemens, D., & Stoffgen, P. (2024). TimerOne. *Arduino Reference*. https://www.arduino.cc/reference/en/libraries/timerone/

Jin, W., Ji, Y., Larsen, D.H., Huang, Y., Heuvelink, E., & Marcelis, L.F.M. (2023). Gradually increasing light intensity during the growth period increases dry weight production compared to constant or gradually decreasing light intensity in lettuce. *Scientia Horticulturae*, ***311***, 111807. https://doi.org/10.1016/j.scienta.2022.111807

Liu, J., & van Iersel, M.W. (2021). Photosynthetic physiology of blue, green, and red light: light intensity effects and underlying mechanisms. *Frontiers in Plant Science*, ***12***, 619987. https://doi.org/10.3389/fpls.2021.619987

Lubis, F.B., & Yanie, A. (2022). Implementasi Pulse width modulation (pwm) pada penyaluran limbah cair pupuk kelapa sawit berbasis arduino. *Journal of Electrical Technology*, *7*(2), 39–46.

Neo, D.C.J., Ong, M.M.X., Lee, Y.Y., Teo, E.J., Ong, Q., Tanoto, H., Xu, J., Ong, K.S., & Suresh, V. (2022). Shaping and tuning lighting conditions in controlled environment agriculture: A review. *ACS Agricultural Science and Technology*, ***2***(1), 3–16. https://doi.org/10.1021/acsagscitech.1c00241

Runkle, E. (2017). Effects of blue light on plants. https://irjet.net/archives/V4/i6/IRJET-V4I6475.pdf

Sena, S., Kumari, S., Kumar, V., & Husen, A. (2024). Light emitting diode (led) lights for the improvement of plant performance and production: A comprehensive review. *Current Research in Biotechnology*, ***7***, 100184. https://doi.org/10.1016/j.crbiot.2024.100184

Shishegar, N., & Boubekri, M. (2016). Natural light and productivity: Analyzing the Impacts of daylighting on students' and workers' health and alertness. *International Journal of Advances in Chemical Engineering and Biological Sciences*, ***3***(1), 72–77. https://doi.org/10.15242/IJACEBS.AE0416104

Siminovitch, M. (2014). Understanding LED Illumination. *Physics Today*, ***67***(7). https://doi.org/10.1063/pt.3.2452

Syukriyadin, S., Sara, I.D., Syahrizal, S., Fauzan, M., & Fajri, M. (2024). Kangkung microgreen growth analysis under T5 LED lighting using solar PV. *IOP Conference Series: Earth and Environmental Science*, ***1356***, 012016. https://doi.org/10.1088/1755-1315/1356/1/012016

Tamilselvi, N.A., & Arumugam, T. (2018). Microgreens-a multi-mineral and nutrient rich food. *Chronica Horticulturae*, ***58***(1), 14–19. www.sendacow.org

Tang, W., Guo, H., Baskin, C.C., Xiong, W., Yang, C., Li, Z., Song, H., Wang, T., Yin, J., Wu, X., Miao, F., Zhong, S., Tao, Q., Zhao, Y., & Sun, J. (2022). Effect of light intensity on morphology, photosynthesis and carbon metabolism of alfalfa (*Medicago sativa*) seedlings. *Plants*, ***11***(13). https://doi.org/10.3390/plants11131688

Treadwell, D., Laughlin, W., Landrum, L., & Hochmuth, R. (2020). Microgreens: A new specialty crop: HS1164, rev. 9/2020. *Horticultural Sciences Department*, ***2020***(5), 1–3. https://doi.org/10.32473/edis-hs1164-2020