The Effect of LED Lighting on Lettuce Growth in a Vertical IoT-Based Indoor Hydroponic System

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Abstract—Indoor vertical hydroponics is one of the most recent agricultural technologies introduced. It is a method of growing plants in vertically stacked layers using water and nutrient solutions instead of soil. When cultivating such a system, utilizing and maintaining the quality of water and nutrients is critical for plant growth. Additionally, LED growth lights have a significant effect on plants. Despite developments in LED lighting and Internet of Things based smart agriculture systems, there is a lack of information on LED lighting for hydroponically grown crops in vertical culture since vertical agriculture is a relatively new field of study. Thus, this research aimed to develop an Internet of Things based agricultural system to automated control LED-based artificial lighting on crop cultivation and explore the effects of different LED lights on plant growth. Numerous sensors were installed and monitored to measure the Potential of Hydrogen ion, Electrical Conductivity, and other parameters in the Internet of Things based system. The Blynk application can remotely control the LEDs and monitor the entire sensor and actuator. As for the effects of LED light, particularly the red and blue light, we utilize a case study of three LED grow light models from the manufacturer as light treatments for cultivating green leaf lettuce (Lactuca sativa). The result showed that increased red light (RED/BLUE = 2:1) increased plant height, leaf width, and leaf length on both harvesting days (10 and 20 day after transplanting). The lettuce plant shape and size signify that the lettuces in each tier are of a good standard and comparable in size.

Keywords—vertical agriculture, vertical farming, LED lighting, hydroponics, Internet of Things (IoT), ESP8266

1 Introduction

With climate extremes and global warming on the rise, there may be limits on water and mineral nutrients and the reduced availability of work and access to soils and fertile soils. Vertical agriculture was recommended to overcome the shortage of land and resources by improving water and nutrients productivity, fully controlling environmental factors, and limiting exchanges with the external environment [1, 2]. Vertical Farming is an agricultural approach for cultivating vertically stacked production within protected environments using available agricultural technologies, such as traditional soil systems, hydroponics, and aeroponics [3].

One of the agricultural technologies employed in vertical agriculture is the hydroponic system. Vertical hydroponics has been presented as enhancing productivity per unit by improving crop output in the vertical dimension. This farming technique is soilless that utilizes a liquid nutrient solution in which the plant's roots are underwater in the solution or grown in an artificial medium. Various plants may be cultivated in a hydroponic approach, including herbs and leafy plants, including lettuce, kale, and cherry tomato [3].

Light is the principal environmental influence affecting plant growth and development in an indoor vertical farm [4-8]. Terrestrial sunlight consists of ultraviolet (UV), visible light, and infrared radiation, in which visible light accounts for almost half of the absorption spectrum. UV radiation has a wavelength of 100-400 nm, visible light has a wavelength of 400-700 nm, and infrared radiation has a wavelength of 700-1000 nm. Although there is a wide range of terrestrial sunlight, plants can only use the spectrum of visible light to produce photosynthesis, and this narrow spectrum is recognized as the photosynthetically active radiation (PAR) [9]. According to Cometti et al. [10], the quality and quantity of solar radiation they receive are very dependent on their photosynthetic activity. Different pigments, such as chlorophyll A and B for red (650-700 mm) and blue (420-460 nm), are responsible for the capture or absorption of the different light spectrum [11]. Theiler et al. [8] determined that the wavelength perceived by plant photoreceivers and pigments in the visible light spectrum is 500-600 nm. As a result, supplementary lighting has been developed to support crop production in vertical farms, especially in a closed and shaded environment.

As a growing light, the LED is a growing technology compared to conventional lighting sources such as high-pressure sodium lights (HPS) or fluorescent lights. The benefits of LEDs include optimizing illumination spectrums to the particular wavelengths required by crops, reducing energy saved in the conversion of energy to photon energy, minimum thermal emission, and longer life [12]. In addition, the luminous efficiency of LED-based solid-state lighting is still being improved, and significant gains are provided with a novel color-mixed solid-state lighting technology [13].

LED technology has been evolving effectively to improve the efficiency of electricity conversion to light for photosynthesis. There are increasing studies that indicate that the device's overall efficiency is highly dependent on the lighting strategy [14]. Many studies have been conducted to investigate the use of various color LEDs to accelerate plant growth compared to plants grown in normal solar irradiance [4]. In literature, red and blue light are used in current LED-based artificial lights for agricultural production because these spectra efficiently stimulate leaf photosynthesis. Singh, Basu, et al. [15] found that red and blue light is the best for plant photosynthesis. Such spectra show the peak absorption values of photosynthetic pigments and plant leaves [7]. Thus, plant responses to varied red and blue light ratios have been studied extensively.

Aside from the advances in essential LED growth lights, a smart agricultural system based on IoT has recently been widely adopted in a vertical farms. Smart farming incorporates information and communication into machines, equipment, and sensors for use in agricultural production systems [16-20]. Sensing systems and devices or actuators are used in farming to monitor the environment, such as humidity, temperature, luminosity, water pumps, lighting, fans, water level, temperature, pH, turbidity, and so on [16, 21, 22]. Device communication, such as a wireless microcontroller module, Arduino, Raspberry Pi, and others, was collected and transmitted using TCP-based or UDP-based communication systems. The smart system connects data to the cloud, which can be done remotely via the internet, including plant system control and monitoring through web-based or mobile applications to view sensor data [16, 21-23]. As can be seen, the entire IoT smart system allows us to adjust production in the vertical system based on plant cultivation, environmental factors, and other functional and non-functional requirements.

As previously stated, while advancements in LED lighting and IoT-based smart agriculture systems have been made, there is a shortage of information on the use of LED lighting for hydroponically grown crops in vertical culture, and vertical agriculture is a relatively new field of study. Thus, this research aimed to develop an IoT-based agricultural controlling and monitoring system to automated control LED-based artificial lighting on crop cultivation using an indoor hydroponic system and investigates the effects of varying grow light LEDs on plant growth, particularly the red and blue light, by utilizing a case study of three LED grow light models from the manufacturer as light treatments for cultivating green leaf lettuce (Lactuca sativa).

2 Material and methods

2.1 IoTs hydroponics system

The IoT-based indoor hydroponic system consists of three main parts: sensor and actuator systems, WiFi module and Blynk server, and vertical multitier hydroponic system. The overall block diagram is shown in Figure 1, and the working principle is given as a flowchart in Figure 2.

There are many parameters to stay within a certain range in a hydroponic system, including pH, electrical conductivity (EC), ambient temperature, and flow sensor. Digital Temperature Sensor DS18B20 is a waterproof sensor with low power consumption. It has a temperature range of -55 to 125°C with a 0.5°C accuracy from -10°C to +85°C. It is an effective sensor for accurate aquaponics temperature measurements. The EC sensor (DFRobot, DFR0300-V2) was used to measure the EC, and to determine the amount of the pH of the nutrient was the pH sensor (DFRobot, SEN0106-V2). An electromechanical relay controlled the LED lights and water pumps. These sensors and actuators are connected to the microcontroller to monitor and control the various parameters of the hydroponic system.

The proposed system is a low-cost microcontroller-based device with a WiFi module ESP8266 that controls all interconnected modules to keep the system running. The ESP8266 serves as a node, displaying sensor values on LCD and transmitting temperature sensor, EC, pH, LED lights, water pump values to the Blynk server. The vertical hydroponic system will automatically and independently modify and maintain these parameters in their proper values without the need for human involvement. Furthermore, all the acquired data can be monitored from the IoT platform on any smart device. This can be explained in detail in the next section concerning the vertical hydroponic structure.

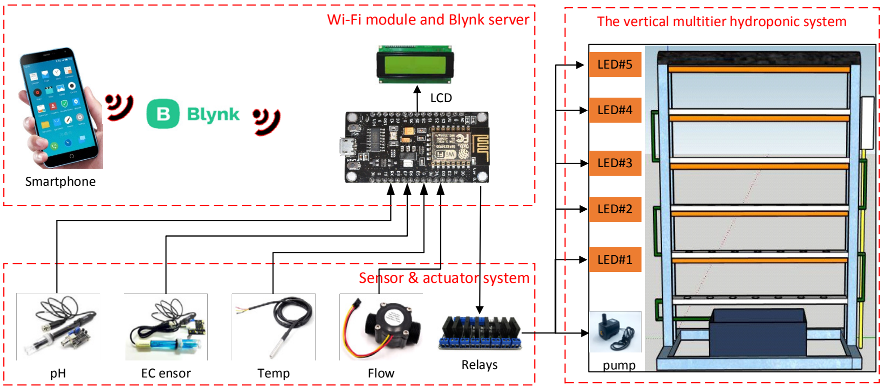


Fig. 1. Block diagram of overall system

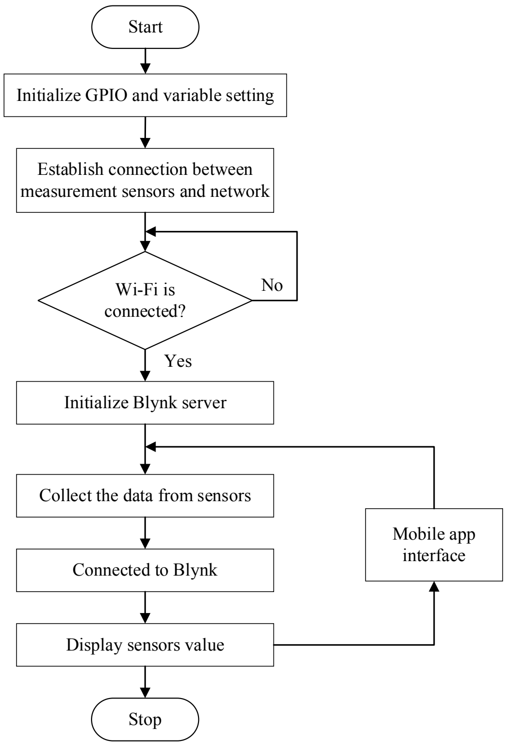
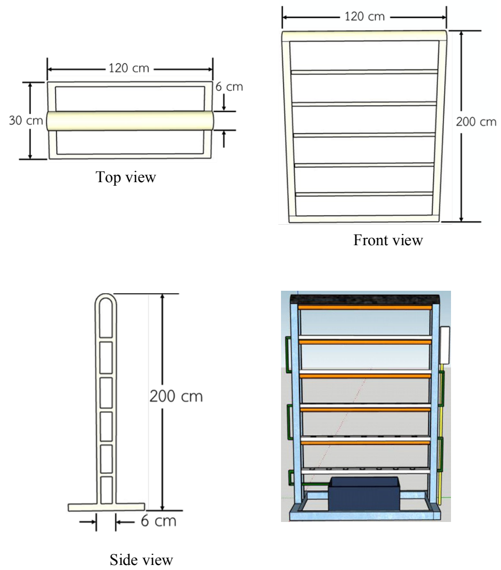


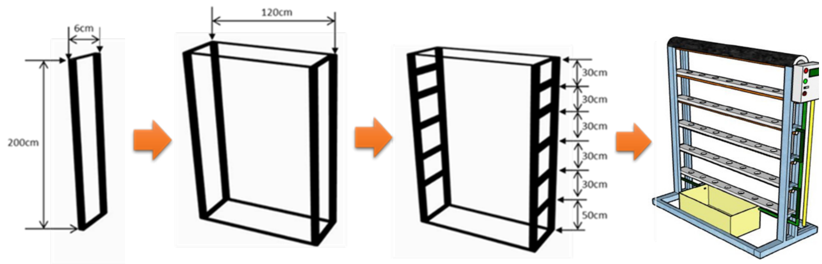
Fig. 2. Flowchart of ESP8266 programming

2.2 Plant materials and growth environments

The vertical multitier hydroponic system. A five-tiered hydroponic system with a height of 200 cm and a width of 120 cm was designed for an indoor vertical hydroponics system (Figure 3). Each tier included a rectangular tray connected with small polyvinyl chloride (PVC) pipes. The rectangular tray, which can be opened and has a length of 120 cm, has six holes for inserting a vegetable bowl in which plants were grown on each tier treatment. As the fertigation reservoir, a 30 liters fertigation tank was used to pump water containing fertilizer into the hydroponic unit. The step of assembling the vertical multitier hydroponic system can be shown in Figure 3. All components can be purchased locally to minimize costs drastically and conveniently produced and assembled.



(a)



(b)

Fig. 3. (a) Dimensions of vertical hydroponics system (b) Step of assembling the workpiece

Growth environments. The experiment was conducted in the Creating Technological Innovation for the Community Research Center, Nakhorn Pathom Rajabhat University, Thailand. In this project, green leaf lettuce was chosen as the experimental plant. Seeds of leaf lettuce were germinated in sponge sheet size 30 pieces and hydroponically grown for 15 days on the five-floor of the vertical hydroponics system. The light intensity was maintained at a photosynthetic photon flux density (PPFD) of 50±3 μmol/m^2/s for 24 hours with LED grow light lamps. After 15 days of germination, the uniform-sized lettuce seedlings at the 4-leaf stage were transplanted to a small bowl (5 x 4 cm) to support the plants' roots before being placed to the nutrient and grown for 30 days after transplanting (DAT).

This work used a hydroponics nutrient concentrate containing two solutions A and B, which was obtained from a local company specializing in hydroponics equipment and supplies. This solution is diluted first with standard tap water, then its pH and EC are calculated to be optimal for the lettuce within defined ranges. The electrical conductivity and pH of the nutrient solution were held constant during the experiment at 0.6-0.8 mS/cm and 6.0-6.5, respectively. Those levels corresponded to the optimal lettuce range in a hydroponic system [5]. During the experiment, the nutrient solution was adjusted every seven days.

2.3 Light treatments

This study aims to investigate the effects of varying grow light LEDs on plant growth in indoor lettuce cultivation. Many research has shown that a combination of red and blue LEDs is the most effective LED light for plant growing [4]. As a result, the light treatment in this study was applied to three LED growing light models from the manufacturer as light treatments for cultivating green leaf lettuce in a case study. Figure 4. shows the spectral composition in each model from the manufacturing specification. LEDs were installed in each tier with a distance of 30 cm. between LEDs and the top of the hydroponic tray. The following are the features of various LED lighting treatments and installations:

- T8 GROW LIGHT Daylight was installed on Tier 5
- T8 GROW LIGHT Warm White was installed on Tiers 3-4
- T8 GROW LIGHT RW was installed on Tiers 1-2

As shown in Table 1, the light intensity from each LED generates a comparable amount of light with 51-53 μmol/m^2/s and 18 W power consumption. The vertical hydroponic system will automatically turn on the lighting system for 16 hours each day [4, 7].

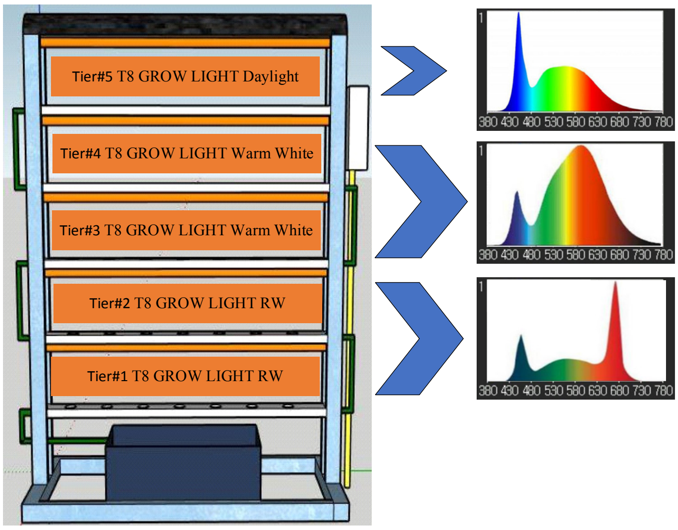


Fig. 4. Light spectra from the manufacturing specification used in the experiments

Table 1. Different LEDs light specification

Model	Power (W)	Tiers	Number of LED (pcs)	PPFD: 30 cm (µmol/m²/s)
T8 GROW LIGHT Daylight	18	5	100	51.01
T8 GROW LIGHT Warm White	18	3,4	100	52.85
T8 GROW LIGHT RW	18	1,2	100	52.54

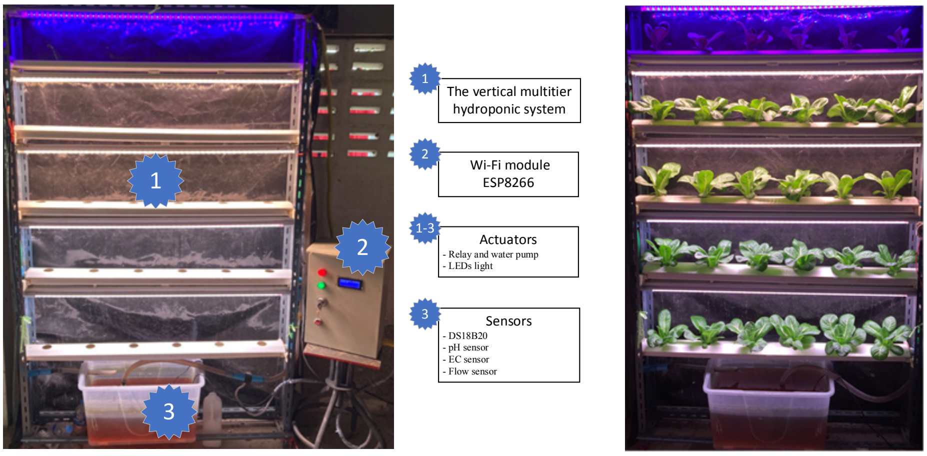
2.4 Data collection and analysis

The data was collected for 30 days, starting on the first day after the seedlings were transplanted to the hydroponic vertical garden system. Various sensors, pH, EC, ambient temperature, relative humidity, and flow sensor status, were measured and recorded. As for the measurement of the light spectra of treatments, the peak wavelengths, light intensity, and PPFD of the light sources were measured using a handheld spectrometer (spectral PAR meter model PG100). Five plants were chosen at random from each treatment to measure plant growth. It was measured every three days until 30 days after transplanting.

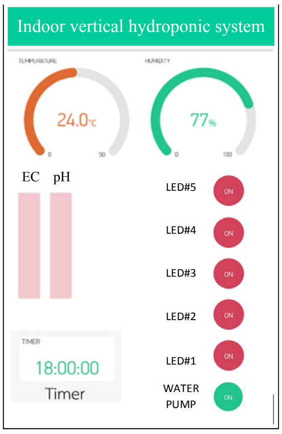
3 Results

3.1 IoT controlling and monitoring system

The proposed vertical IoT-based indoor hydroponic system for plant growth with various LED lighting has been implemented and installed, as shown in Figure 5. It consists of sensor and actuator systems, an ESP8266 WiFi module, and a vertical multitier hydroponic system. This work employed a Blynk server for all communications between the smartphone and all sensor values. This can also control the LEDs remotely and display the whole sensors and actuators via the Blynk application (Figure 5).



(a) (b)



(c)

Fig. 5. (a) Setup of IoTs vertical multi-tier hydroponics system (b) The growth of lettuce (c) Blynk application screenshots

3.2 Spectrometric measurements

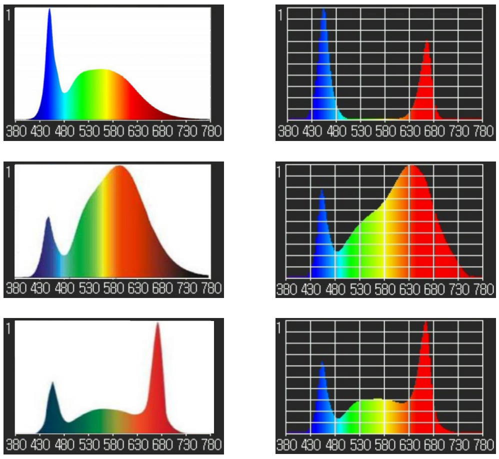
The light spectra of three LED grow light models, involving peak wavelengths, light intensity, and PPFD, were measured with a portable spectrometer (spectral PAR meter model PG100). The results are given in Table 2.

- LED Grow Light Warm White and LED Plant Grow Light RW treatments have similar peak wavelengths of 664 nm and 633 nm, respectively, while the LED Grow light Daylight treatment had a peak wavelength of 453 nm.
- The highest light intensity value was 7,000 LUX for the LED Plant Grow Light RW treatment, 6,000 LUX for the LED Plant Grow Light warm white and 743 LUX for the LED Plant Grow Light Daylight treatments.
- The PPFD value of the wavelengths was highest at LED Grow Light Warm White, and it was followed by LED Plant Grow Light RW and LED Grow Light Daylight treatments, respectively.

Table 2. Different LEDs light specification

Model	**Peak wavelength (nm)**	**Light intensity (LUX)**	**PPFD: 25 cm (μmol/m^2/s)**
T8 GROW LIGHT Daylight	453 (Blue)	743	68
T8 GROW LIGHT Warm White	664 (Red)	6,000	130
T8 GROW LIGHT RW	633 (Red)	7,000	100

The light spectra of LEDs were compared to those specified by the manufacturer and those obtained using a spectrometer (Figure 6). From the light spectra it can be seen that T8 GROW LIGHT Daylight varies significantly, whilst the other one is fairly close.



(a) (b)

Fig. 6. LEDs light spectra were compared (a) Manufacturing specification (b) spectrometer (spectral PAR meter model PG100)

3.3 Effects of different LEDs treatment

The results of the lettuce's development were observed after being experimented on onto the vertical hydropic system. After 15 days of germination, the uniform-sized lettuce seedlings at the 4 leaf stage were transplanted to vertical hydroponic systems and grown for 30 days after transplanting. Lettuce from each treatment was chosen to measure the growth characteristics. Plant height, leaf width, and leaf length were measured regularly at both harvesting phases (10 and 20 DAT). The statistical analysis was processed by one-way analysis of variance (ANOVA) using SPSS version 22, as shown in Tables 3 and 4. According to our observations, an increasing proportion of R light (R/B = 2:1) increases plant height, leaf width, and leaf length on both harvesting days. The lettuce plant form and size results showed that the lettuces in each tier are of a good standard and comparable in size (Figure 7).

Table 3. Lettuce's growth characteristics are cultivated under various R/B light treatment ratios at 10 DAT

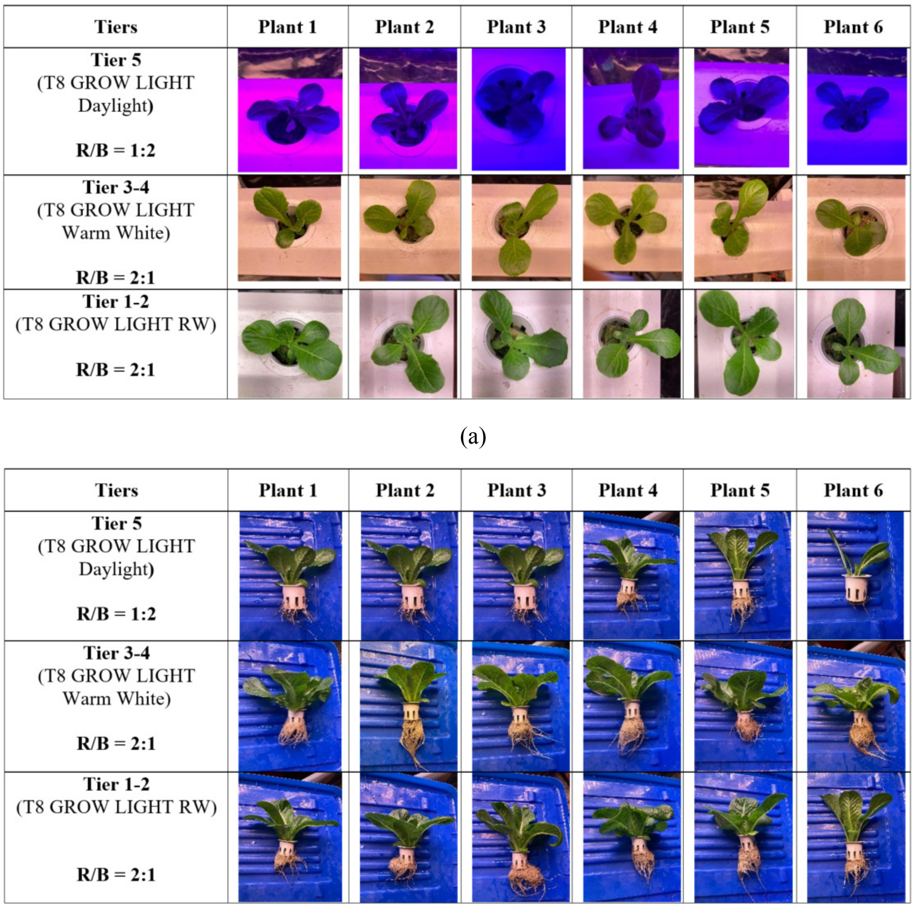
Tier	Treatments	Plant height (cm)	Leaf width (cm)	Leaf length (cm)
Tier 5	R/B = 1:2	6.16 ± 0.35[a]	2.63 ± 0.26[a]	5.24 ± 0.30[a]
Tier 4	R/B = 2:1	7.28 ± 0.32[b]	3.64 ± 0.37[b]	6.45 ± 0.42[b]
Tier 3	R/B = 2:1	6.33 ± 0.29[a]	4.31± 0.29[c]	6.17 ± 0.40[b]
Tier 2	R/B = 2:1	6.59 ± 0.30[a]	4.59 ± 0.37[c]	6.53 ± 0.39[b]
Tier 1	R/B = 2:1	8.42 ± 0.35[c]	4.21 ± 0.35[c]	8.15 ± 0.42[c]

Mean separation within columns by DMRT test at 5% significant level. The values are means ± SD of five separate measurements. Values labeled with different letters in a column are significantly different ($p < 0.05$).

Table 4. Lettuce's growth characteristics are cultivated under various R/B light treatment ratios at 20 DAT

Tier	Treatments	Plant height (cm)	Leaf width (cm)	Leaf length (cm)
Tier 5	R/B = 1:2	11.57 ± 0.18[a]	7.68 ± 0.78[a]	10.81 ± 0.39[a]
Tier 4	R/B = 2:1	12.47 ± 0.25[b]	9.56 ± 0.44[bc]	11.76 ± 0.27[ab]
Tier 3	R/B = 2:1	13.67 ± 0.09[c]	8.77 ± 0.44[b]	13.51 ± 0.30[b]
Tier 2	R/B = 2:1	12.32 ± 0.06[b]	9.13 ± 0.49[b]	12.34± 0.42[c]
Tier 1	R/B = 2:1	13.41 ± 0.34[c]	8.46 ± 0.61[b]	13.68 ± 0.21[c]

Mean separation within columns by DMRT test at 5% significant level. The values are means ± SD of five separate measurements. Values labeled with different letters in a column are significantly different ($p < 0.05$).



(b)

Fig. 7. Lettuce plant shape and size at (a) 10 DAT and (b) 20 DAT

4 Discussions

In the case of the effect of LED treatment on lettuce's growth, compared to the current experiment, the R/B ratio of LEDs may be set to either 1R:2B or 2R:1B, depending on their light spectra. Lettuce plants have earlier been shown to have a higher growth rate; increasing the amount of R light (R/B = 2:1) increased the height of the plants and the width and the length of their leaves. In comparison, various studies on the development of lettuce, particularly those involving red and blue light, have been reported in the scientific literature. A study by Kang et al. [7] investigated the effects of combining green and blue light on leaf photosynthetic rate, growth, and morphogenetic characteristics in lettuce plants. The results show that the highest red ratio produced plants with the largest and widest leaves. As Naznin et al. [24] reported, they evaluated the effects of different red and blue LED lighting combinations on growth, pigment content, and antioxidant capability in lettuce, spinach, kale, basil, and pepper. They reported that increasing the quantity of red light available to such plants increased their height and leaf area. As with earlier studies, Azad et al. [12], investigated the use of low light irradiation with blue (B) and red (R) LED in a plant factory for the growth of red leaf lettuce (Lactuca sativa L. var Lollo rosso) to evaluate growth performance and functional quality. According to the findings, a larger R fraction (R/B = 5:1) considerably enhanced plant growth indices such as plant height, leaf area, specific leaf area, plant fresh and dry weight, and carbohydrate content. By contrast, increasing the B fraction (R/B = 1:5) dramatically enhanced pigment and phenolic compounds' photosynthetic parameters and contents. The authors conclude that high R fractions increase plant development and carbohydrate content. In contrast, high B fractions promote photosynthetic performance and pigment and phenolic component accumulation in red leaf lettuce grown under restricted illumination circumstances.

5 Conclusion

This paper presents the vertical IoT-based indoor hydroponic system for plant growth with different LED lighting. The final goal of this research was to develop smart agriculture for use in a vertical hydroponic system and explore the effects of different LED lights on plant growth parameters.

The vertical IoT-based indoor hydroponic system for plant growth with various LED lighting has been designed and installed. A five-tiered hydroponic system with a height and width of 200 x 120 cm was designed for an indoor vertical hydroponics system. Each tier included a rectangular tray connected with a small PVC pipe. This can purchase all components locally to minimize costs drastically, and it can also be produced and assembled. Numerous sensors were installed and monitored to measure the pH, EC, ambient temperature, relative humidity, and flow sensor status. Regarding system control and monitoring, using the Blynk application, the LEDs can be remotely controlled, view the entire sensor and actuator network.

As for the growth environment, leaf lettuce seeds were germinated in sponge sheet size 30 pieces and hydroponically grown for 15 days on the five floors of the vertical hydroponics system. After 15 days of germination, the uniform-sized lettuce seedlings at the 4 leaf stage were transplanted to a small bowl to support the plants roots before being placed to the nutrient and grown for 30 days after transplanting.

We investigate the effects of varying grow light LEDs on plant growth, specifically the effects of red and blue light, using a case study of three LED grow light models from a manufacturer as light treatments for cultivating green leaf lettuce. LEDs can have an R/B ratio of 1R:2B or 2R:1B, depending on their light spectra. Increased R light (R/B = 2:1) resulted in an increase in plant height, leaf width, and leaf length on both harvesting days (10 and 20 DAT). The lettuce plant shape and size signify that the lettuces in each tier are of good standard and comparable in size.

6 Acknowledgment

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