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Horticulture of Lettuce (*Lactuvasativa L.*) Using Red and Blue LED with Pulse Lighting Treatment and Temperature Control in SNAP Hydroponics Setup

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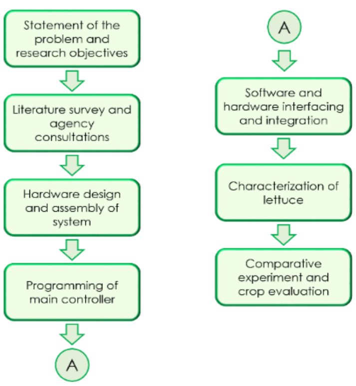
Graphical abstract



Abstract

Among the major concerns of agricultural production includes food safety, environmental impact, efficient energy usage and climate change. To give response to this, the paper introduced the devised indoor farming methodology that utilized red and blue light-emitting diode (LED) as light source for the horticulture of lettuce in Simple Nutrient Addition Program (SNAP) hydroponics setup. The study focused on the evaluation of two experimental setups comparing the conventional SNAP hydroponics to the SNAP hydroponics using LED lights. At the end of the main experiment, the results suggested that LED as light source have a significant effect on the number of leaves ($t (41.7) = 6.07$, $p < 0.05$) and leaf area ($t (48) = 4.39$, $p = 0.05$) of a lettuce. Specifically, the results showed that when the environment of the lettuce was controlled, their capability to grow significantly more and larger leaves increases. Also, the weight obtained using the SNAP with LED lights setup (3.04 kg) was 30% greater than the weight obtained using conventional (2.18 kg) hydroponics setup.

Keywords: Pulse lighting LED, SNAP hydroponics, smart farming, PAR

1.0 INTRODUCTION

Light Emitting Diode (LED) is beginning to be prominent in the indoor growing world with its energy saving features, long lifetime, low cost, and no toxicity. The color of this light vary depending on the cultivated plants and it provides exact illumination. It emits light with the right spectrums necessary for plant and ensures that the photosynthesis is taking place at an acceptable rate [1]. Various studies prove that the use of LED has significantly increased the growth rate of plants such as [2] and [3]. The understanding of plant responses to artificial lighting systems in tightly controlled growth systems and the use of LED as a radiation source for plant research and biotechnology constitutes much of the focus of today.

To date, the response of various plant crops to spectral quality has been studied by growing under different artificial lights including metal halide, high pressure sodium lights and LED. Studies have looked at different color of LED and its various combinations on crop production. However, these studies require human intervention for growing plants. Moreover, past studies only focused on the effect of either light or temperature on plants. As climate change continues to worsen, there is a need to develop a methodology and device that could control the environment, both for light and temperature, for indoor planting.

The main goal of this research is to develop an automated smart planting methodology that focuses on the control of the temperature and the light source (LEDs) for the horticulture of lettuce. This offers a new perspective in the indoor farming technology that requires almost no human intervention and aim for a higher crop yield. The study will be beneficial to crop producers and consumers. Damage of plants because of climate change and typhoons can be minimized through this project. Off-season plants that cost more can be produced throughout the year giving higher return of investment.

2.0 METHODOLOGY

The study is divided into three phases namely: (1) hardware development of the system, (2) software development for the controller of the system and (3) comparative experiment between the conventional SNAP hydroponics setup to the automatic SNAP hydroponics setup that is being proposed in this study. Figure 1 show the main research process flow followed during the course of the development of the research.

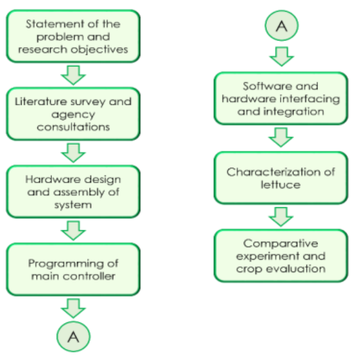


Figure 1 Research process flow of the study

2.1 Hardware Development

The hardware used for the study is an enclosed device wherein the light and temperature parameters are controlled and maintained. Light and temperature sensors are needed for these environmental parameters. The high luminance LED serves as the artificial light source for the plants. Figure 2 shows the actual device used in the study.

Figure 2 Actual photograph of the indoor planting device

The cooling system is used for the control and maintenance of temperature. It is comprised of an inlet fan, exhaust fan, and air conditioning unit. A temperature of 15˚C-21˚C is maintained inside the device. The fans are controlled in a timely basis for air circulation within the device.

The design of the project contains power supply, rechargeable battery, microcontroller unit, temperature sensor, light sensor, real-time clock circuit, relay driver circuit, LCD, SD card reader, inlet and exhaust fans, LED panels, air conditioning unit, and hydroponics setup.

Figure 3 shows the block diagram of system. The power supply produces 5 V and 12 V DC outputs, and it is paired with a 12 V rechargeable battery. The 5 V DC output is used for initializing the microcontroller unit, the real-time clock circuit, the SD card driver, the LCD, and the sensors. The 12 V DC output is used for the 10-minute operation of fans and supplies power for the 45-minute operation of LED modules. The fans can sustain a 104.43 CFM flow rate. The air conditioning unit is a 540 W window type unit with 5600 kJ/h cooling capacity responsible for maintaining a 15ºC-21ºC temperature within the device.

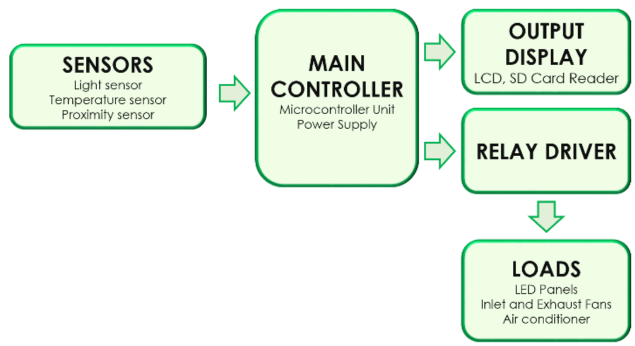


Figure 3 Block diagram of the indoor planting device

The assembly of the system is shown in Figure 4. It shows the different subsystems of the automated indoor planting device and where are they located within the device.

The Main Controller subsystem serves as the brain of the whole device. This subsystem facilitates the control, schedule and driving of the system.

The Cooling subsystem regulates the temperature and air in the device. Inside and outside temperature sensors are installed to monitor the temperature measurement.

The Lighting subsystem comprises of the main panel and side panels. It is composed of high luminance red and blue LEDs that serve as the light source. The fans, LED panels, light sensor and temperature sensors are connected to the MCU to establish the set operations.

The SNAP hydroponic setup holds the plant samples and provides the nutrients needed by the plant to grow.

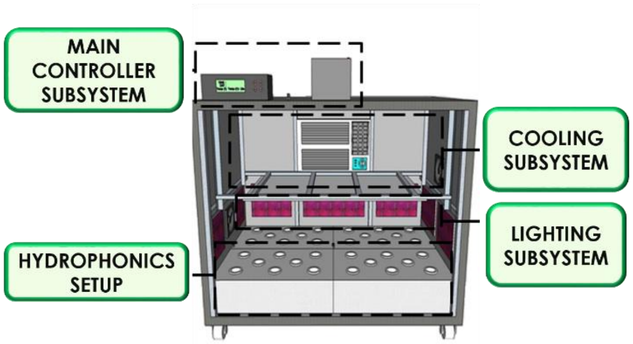
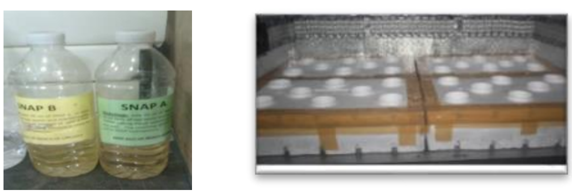


Figure 4 Assembly of the indoor planting device

The hydroponics setup in this study uses a solution developed by the Bureau of Plant Industries (BPI) in the Philippines. The solution is called simple nutrient addition program, hence SNAP, solution that is commonly used in growing crops such as lettuce, celery and cucumber in case that soil is not available. Figure 5 shows the SNAP hydroponics setup and solution used in the study.



(a) (b)

Figure 5 (a) SNAP solution and (b) hydroponics setup used in the study

2.2 Photosynthetically Active Radiation (PAR)

One of the most important parts of this study is understanding the concept of photosynthetically active radiation (PAR). Basically, PAR determines how much photons are available for the plants to use in photosynthesis given the 400 nm to 700 nm wavelength range. [5] The unit for measuring PAR, micro-moles per square meter second (μmol/m^{2}s), indicates how many photons in this spectral range fall on the plant each second

Every crop has different PAR needs. Some plants need shorter wavelengths (such as blue) at earlier stages and longer wavelengths (such as red) at latter stages of their crop cycle.

Section 2.4 of this paper describes the characterization done to identify the number and color of LEDs to be used for the optimal growth of lettuce.

2.3 Software Development and Process Control Flow

The software development is focused in the programming of a PIC16F877A 8-bit microcontroller. It has two main parts: the process control of pulse lighting LEDs and the temperature control system.

According to the results of the study of Harun et. al [4], the best lighting to be used for indoor plants for optimal growth is pulse lighting system. Using a pulse lighting scheme, the plants will be able to receive 45 minutes of ON time for the LEDs and 15 minutes of OFF time for the LEDs. This will give the plants a total of 18 hours photosynthetic time which is 50% longer than the normal 12-hour average photosynthetic time. This approach is reported to have a good result in indoor farming of crops and hence adapted to this study. Figure 6 shows the process control flow of the lighting of the LEDs.

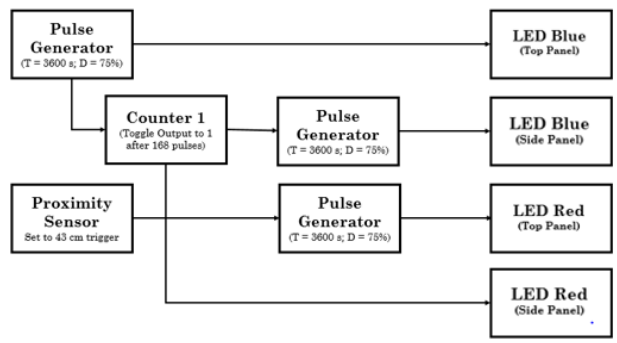


Figure 6 Process control flow of the pulse lighting system

In this study, the lighting schedule is done automatically unlike in the previous studies by using the microcontroller and the process control system shown in Figure 6. Moreover, since at earlier stages of the lettuce crop cycle, only blue light is needed, only blue LEDs are used at the onset. After several days and lettuce starts to grow it needs red LEDs. For this, a proximity sensor is used to trigger the red LEDs after the lettuce reached a height of about 7 cm (half of the lettuce average lettuce height in the Philippines).

The air conditioner sets the desired temperature range ideal for the growth of the lettuce. A simple control system is used to control the operation of the inlet and exhaust fans for proper ventilation. This is used to remove all the excess heat produced by the LEDs inside the device and circulate the air. The inlet and exhaust fans are installed to maintain the humidity inside the system and to ensure the proper air circulation. The fans turn on for 10 minutes every hour. It turns on at the 49th minute and turns off at the 59th minute.

Although the temperature of the device is set by the air conditioner, sudden burst of heat coming from the LEDs must be taken out immediately from the system. Proper operation of inlet and exhaust fans take care of this matter.

Control based on time scheduling is used in this paper because growing of plants heavily rely on time schedule rather than response on error. Hence, traditional PID controllers and other control methods are not considered on this paper but may be further investigated in future studies.

2.4 Determination of the Number of LEDs

This experiment determines how many LEDs are going to be used in the device for optimal plant growth.

First, the SNAP hydroponics setup is prepared. The seedlings are grown in Styrofoam cups that are submerged into the water and nutrient solution. There are four growing boxes with eight plant samples each for a total of 32 plants. The growing boxes contain 10 liters of solution that is enough for the entire growing stage until harvest time.

The amount of light intensity of red and blue LEDs on is first tested on the lettuce samples to verify the right illumination needed for the sufficient plant growth. The growth of lettuces is observed and recorded. Based on the result (see section 3.1) the researchers are able to correlate the PAR values measured to the number of leaves and leaf area. This enable them to identify the number of LEDs sufficient for optimal growth of the lettuce.

2.5 Comparative Experiment

After the number of LEDs to be used is determined in first experiment, a comparative test is done to compare the conventional SNAP hydroponics setup – Treatment A and the automated hydroponics setup – Treatment B.

The two treatments uses the same setup of 32 plants using 10 liters of SNAP solution. The two setups are grown simultaneously and are harvested after 30 days.

After which, their number of leaves, leaf area and weight are compared. These parameters are chosen because leaf measurements are required in most physiological and agronomic studies involving plant growth [6]. Proximate analysis of the lettuce produced in each treatment are also compared to assess the difference between their macronutrient content.

3.0 RESULTS AND DISCUSSION

The following section gives the results and discussion of the two experiments done in the methodology of this paper.

3.1 Determination of the Number of LEDs Results

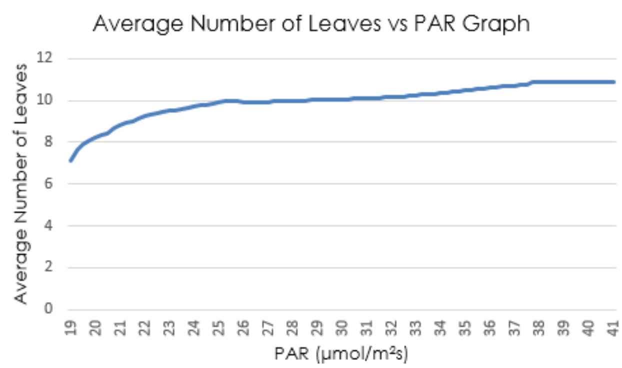
Table 1 gives the result of the experiment discussed in section 2.4.

Table 1 Average measurement of par, number of leaves and leaf area per box

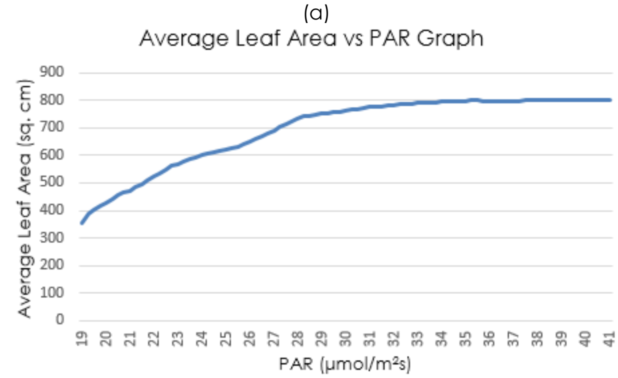
Growing Condition	PAR (μmol/m²s)	Number of Leaves	Leaf area (sq. cm)
Box 1	19.00	7.13	356.34
Box 2	19.13	7.63	386.39
Box 3	19.63	7.88	403.33
Box 4	21.00	8.63	471.06

The amount of initial PAR chosen is based on researchers' intuition of much light will the lettuce need to grow and adjust from thereon. It is evident from Table 1 that as the PAR increases, the number of leaves and leaf area also increases. Hence, the amount of PAR can be further increased to obtain a better lettuce in terms of average number of leaves and leaf area.

Based on the area of the device's chassis, the number of LEDs accommodated is projected. Another experiment is done and is seen that the number of leaves and leaf area saturated at about 38 μmol/m²s. Figure 7 shows the graph of the leaf area and average number of leaves obtained after increasing PAR values iteratively. Hence, a total of 346 LED chips (38.8 μmol/m²s.) are used.



(a)



(b)

Figure 7 (a) Average number of leaves and (b) leaf area in sq. cm values measured against corresponding PAR

3.2 Comparative Experiment Results

Table 2 shows the result of the comparative experiment described in section 2.5.

Table 2 Average measurement of number of leaves, leaf area and plant weight of two experimental setups

Setup	Number of Leaves	Leaf Area (sq.cm)	Plant Weight (g)
Treatment A	5.72	419.23	2184
Treatment B	10.88	800.94	3040

From the results, it shows that the proposed SNAP hydroponics setup yielded much higher results in all of the three parameters. These results suggest that lettuce harvested using the proposed hydroponics setup is a viable alternative growing method and can be possibly be more marketable compared to the ones harvested using conventional setup.

An independent-sample t-test is conducted to compare the two test setups in terms of number of leaves and leaf area. Both showed a significant difference in the scores for Treatment A (mean = 5.72, Standard Deviation = 4.42) and Treatment B (mean = 10.88, SD = 1.87); t (41.7) = 6.07, $p < 0.05$ for number of leaves and Treatment A (mean = 5.72, Standard Deviation = 4.42) and Treatment B (mean = 10.88, SD = 1.87); t (41.7) = 6.07, $p < 0.05$ for leaf area.

Specifically, the results suggest that when the environment of the lettuce is controlled, their capability to produce more and larger leaves increases. Furthermore, the weight obtained using Treatment B is 30% greater than the weight obtained using Treatment A.

Table 3 on the other hand shows the proximate analysis result of the two treatments. This is done to to test the nutrient content of the lettuce that was produced in both setups.

Table 3 Average measurement of number of leaves, leaf area and plant weight of two experimental setups

Setup	Moisture (%)	Ash (%)	Crude Protein (%)
Treatment A	93.23	1.28	1.59
Treatment B	96.10	0.96	1.61

Notable things on the result is the moisture in Treatment B is greater than Treatment A. It means that the lettuce produced by the proposed methodology, in layman's term, is juicer by a little bit compared to the conventional method.

However, lettuce produced in treatment A is more likely to have the potential to be a fertilizer compared to the ones produced by our proposed methodology because of the lower ash percentage.

And finally, perhaps one of the most important findings is that the treatment B lettuce has a higher protein content than in treatment A the conventional method. It means that in the process of using LED lights, the lettuce did lose its nutritional value.

4.0 CONCLUSION

In conclusion, the automated indoor methodology, with its temperature-controlled environment and LED as light source, provides the needs of lettuce crops for its sufficient plant growth. It is also found out that the PIC microcontroller circuit effectively controls the pulse lighting of LED and functions of fans, and displays the parameters measured within the device through the LCD. The cooling system provides the needed and stable temperature for the entire 30 days. Last, the devised methodology of planting system has the capability to produce lettuce that has significantly more and larger leaves, and has 30% greater in weight compared to conventional method of growing a lettuce.

For future directives of this study, it is recommended to study the flexibly control the ratio of LED lights, consequently the ratio of the red light to the blue light can be adjusted according to different growing stages of plants and to configure the LED device with a controlled beam angle because providing light beam pattern control ensures that a desired amount of light is emitted to targeted plants with minimal wastage of light.

For implementation, it is recommended to consider vertical farming in order to maximize the space and the use of the cooling system.

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