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The Effect of LED Grow Light Photoperiods on Indoor Hydroponic Lettuce Farming

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ABSTRACT

With the recent advancement in Internet-of-Thing (IoT) technology, smart farming has rapidly evolved as an alternative solution to improve the effectiveness of plant growth and provide a better farming management. The implementation of smart farming involves the use of technology such as big data, the internet of things (IoT), and cloud servers. It is widely known as precision farming because the process of plant growth is managed by software and a sensor-monitoring system. The applications of smart farming are widely implemented in indoor farming especially hydroponic farming. Hydroponic indoor farming is a fast-growth sector due to the lack of land for agriculture caused by urbanization. For indoor farming, grow-light is a crucial factor for plant growth. The most effective and commonly used grow light is the Light Emitting Diodes (LED) grow light. The utilization of LED grows light offers many advantages over traditional grow lighting including less power consumption, generating lower heat and recyclable. Multiple research and investigations have been done on LED's wavelength and intensities effect on the plants. However, the duration of exposure to LED grow light on the plants has the most significant influences on the growth rate of plants. In this project, an investigation into the photoperiods of the LED grow-light has been deployed for lettuce. The photoperiods are 14 hours of LED, 8 hours LED, combination of 8 hours sunlight and 3 hours LED, and compare with 8 hours sunlight. The presented results concluded that 14 hours of LED grow light duration on hydroponic vegetables has the most promising growth rate in indoor hydroponics lettuce farming.

1. Introduction

Smart agriculture or more commonly known as smart farming is a rising field that provides multiple benefits of digitization by utilizing big data, the internet of things (IoT), and artificial intelligence [1]. Generally, smart farming focuses on two major fields of interest which are precision farming and automation system in agriculture [2]. Implementations of precision farming focus on manipulating certain variables that can maximize plant growth such as humidity, fertilizers, and soil

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moisture. Increasing food production has always been a difficult task in the farming industry. In addition to this, there are currently millions of people worldwide that suffer from food shortages due to food insecurity. Some of the causes that influence food shortage are lack of access to farming lands, fast-paced population growth, and climate changes [3]. In short, the situations of severe hunger and malnutrition need to be addressed and overcome with all resources of a certain country. Many implementations of smart farming have been done to increase yields, for instance in soil management, irrigation technologies, and also adapting food production to climate changes [4]. Meanwhile, in Malaysia, SM4RT TANI has provided IoT and cloud solutions to assist local farmers in increasing their farming efficiency and also the amount of yield [5]. The platform that is provided by SM4RT TANI, has increasingly changed the perception of smart farming for local farmers by enabling them to obtain accurate readings and information seamlessly in real-time [5].

Generally, indoor farming is on a smaller scale such as hydroponic systems and crop beds. Meanwhile, outdoor farming is operated in large fields such as orchards and arable lands [6]. The most common utilization of an indoor farming system is the hydroponic system, it is a method of growing plants by using the mineral nutrient solution without the presence of soil [7]. The term Hydroponics was from a Greek word, whereas hydro meant water and ponos' meant labour [8]. The growing plants in the hydroponic system can also be divided into two, which are liquid hydroponic systems and also aggregate hydroponic systems. For utilization of a liquid system, it does not have a supporting medium for the plant roots; while the aggregate has a solid medium to provide support [9]. The hydroponic technique, a soil-less application of farming, immerses the roots of the plants into a nutrient solution [10]. There are several types of hydroponic systems which are deep water culture (DWC), Nutrient film technique (NFT), wick system, drip system, and aeroponics. These systems provide a more accurate way of farming and also reduce the challenges of plant growth facing climate changes and those facing malnutrition, as this environment is more controlled. Treated wastewater was found to be reusable for irrigation of edible crops with a hydroponic setup [11]. A study investigated that the parameters used to study the edible quality of lettuce increased when the lettuces were exposed to LED lights for a longer period of time [12].

The application of a hydroponic system consists of a few key elements (got problem) to make sure that the plant growing cycle is at the optimum environment. The elements are the Light Emitting Diode (LED) growing lights, growing medium and nutrient solutions. LED grow lights are luminaries with the use of LED chips in a modern and efficient way to produce light for growing plants [13,14]. Colour variations of the LED have been shown to have a direct impact on plants' growth rate [15,16]. Most studies have investigated the effects of the red and blue wavelengths of LED grow light; however, additional lighting has been shown to also help in plant growth. Most studies have shown that various wavelengths of light influence the growth rate of plants. Some may increase the growth rate of certain areas such as the length of leaves and the width of leaves, but a different wavelength is required for the elongation of stems. Uncovering the accurate wavelength, intensity and sequencing will allow farmers to maximize the growth rate of the plants while maintaining the health and plant quality. The objectives of this project are to investigate the effect of LED grow light photoperiods on the indoor hydroponics lettuce farming. Lettuce is chosen due to its short growth cycle and relatively distinctive size of leaves for measurement.

2. Methodology

The type of hydroponic system used in this project is deep water culture system. The incorporation of this hydroponic system consists of several key elements which are the LED grow lights, growing medium, nutrient solutions, and air pump. First and foremost, the setup of the system consists of four racks that are allocated to plant the seeds and also a bottom tank (main tank) as the place to store the water. Water pumps are used to regulate the solution into each of the four upper racks. The water pump not only regulates the solution but also serves the purpose of maintaining the oxygen level in the water. Furthermore, each of the upper racks, it will consist of 12 pot areas that must be filled with growing mediums such as Rockwool, coco fibre, or perlite. This media will avoid the seedling to be drifted into the solution and serve as a porous to hold the oxygen and nutrients for the plant to grow. Finally, the nutrient solution is the fertilizers necessary to allow plant root growth. The solution must contain all fourteen essential elements which are; calcium, nitrogen, magnesium, potassium, phosphor, sulphur, boron, chlorine, copper, iron manganese molybdenum, and zinc. Figure 1 provided below is the rough schematic of what the system will look like.

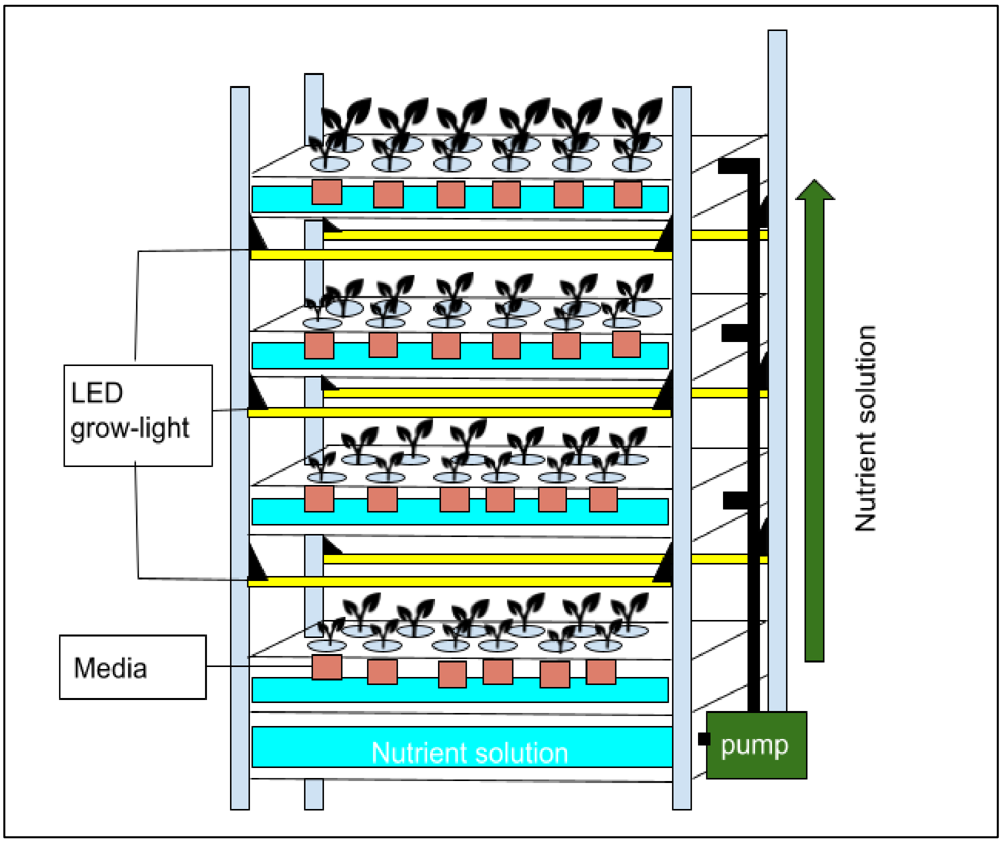


Fig. 1. The schematic diagram of the hydroponic system

This experiment is conducted inside a typical room in a landed premises at tropical country, Malaysia. The average weather temperature was around 28°C to 33°C during the period of experiment being conducted. The room comes with a mild ventilation of air with one window. The setup environment variables of the system such as the humidity and indoor room temperature are kept constant for all racks shown in Figure 1 and monitored through IoT sensors. The room temperature is around 25°C to 28°C with humidity in between 60% to 70% RH. In between the different level of racks, a black cardboard is used to block the upper light source to penetrate the rack below it. The type of LEDs used in this experiment is chip on board (COB) type, with white color spectrum, photons of wavelength from 400nm to 700nm. One unique feature of LED grow lights is that their light output can be precisely controlled and almost instantaneously in real time, which is not possible with high-intensity discharge lamps [17,18]. Dimmable LED lights can be interfaced with quantum sensors and control systems, allowing for adaptive lighting control [17]. There is research to develop an IoT-based agricultural system of growing green leaf lettuce (Lactuca sativa) using automated control LED-based artificial lighting [19,20]. The LEDs are place right above the plants with the distance of 15cm between the LED and top of the pot. Light intensity is measured using lux meter placed at the same level with the top of the pot. The measurement is done at 12pm noon time and the intensity measured is 2.129k lux. Table 1 shows the summary of the environment variables of this project. Romaine lettuce is the plants chosen in this experiment due to its shorter growth cycle and bigger leaves size for measurement.

Table 1
Environmental variables of hydroponics farming set-up

Environmental factors	Measurement
Room temperature	25°C-28°C
Room humidity	60%-70% RH
LED light intensity reaching the pot	2.129k lux
LED wavelength (White)	400nm-700nm

3. Results

Figure 2 illustrates the growth of lettuce over five weeks by utilizing the hydroponic system described in Figure 1. For each rack, the time the plants are exposed to the LED grow light varies. The first rack which is the topmost rack is not exposed to LED grow light as it is only exposed to sunlight for 8 hours (9.00 a.m. -5.00 p.m.). The second rack is exposed to sunlight for 8 hours (9.00 a.m. -5.00 p.m.), and then to LED grow lights for 3 hours (6.00 p.m.- 9.00 p.m.). The third rack was exposed to only an LED grow light for 14 hours (9.00 a.m. – 5.00 p.m.; 6.00 p.m.- 12.00 p.m.). Finally, the fourth rack was exposed to LED grow light for only 8 hours (9.00 a.m. -5.00 p.m.).

Some parameters were kept constant and monitored throughout the investigation. First and foremost, is the nutrient solution, which consists of 2 types of nutrients which are solution A and solution B. The amount that was used for this cycle was 150 ml for each nutrient solution. This was adjusted by taking into consideration of the Electrical Conductivity (EC) value which approximately kept within the value of 0.7 µs/cm. For the pH values of the solution, initially, the solution was quite alkalic, hence 2 drops of pH down solution were used to lower the value to approximately 6.86.

Several parameters were taken into the evaluation to measure the growth rate of plants on each rack. The first parameter is the number of leaves and branches on each sprout. As there will be three seeds that will be put into each cup, the average or the common trend on the number of leaves and branches will only be taken into consideration. Next, are the width and the length of the leaves. The length of the leaves is taken from the tip of the leaf to the stem of the plant. But, for the early stages of growth, the leaf may only grow partially (not until the stem of the plant), hence the values will be taken till which part it has successfully grown. For the width of the leaf, it is taken vertically. Nonetheless, the value that is taken is the height of the stem. The measurement is taken from which it is visible from the growth media until the end of which the stem is split into several branches. It has been noticed that the plants that were grown longer under the LED grow lights have been shown to have healthier and larger leaves.

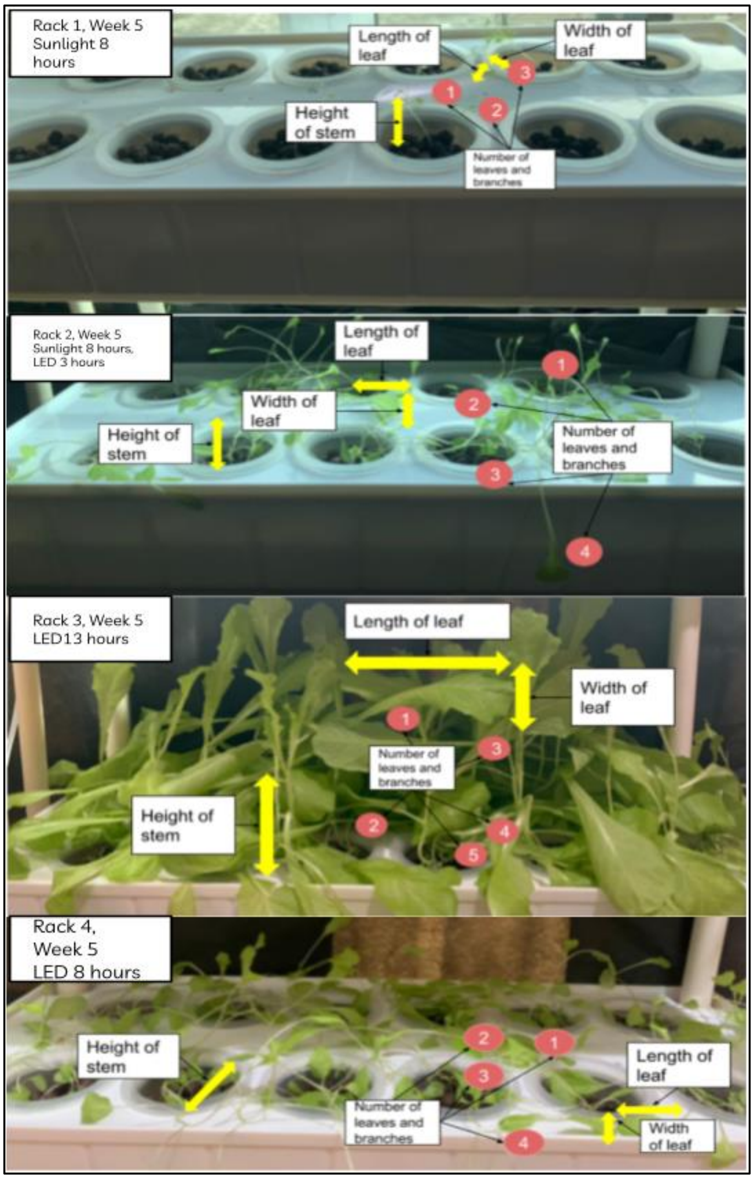
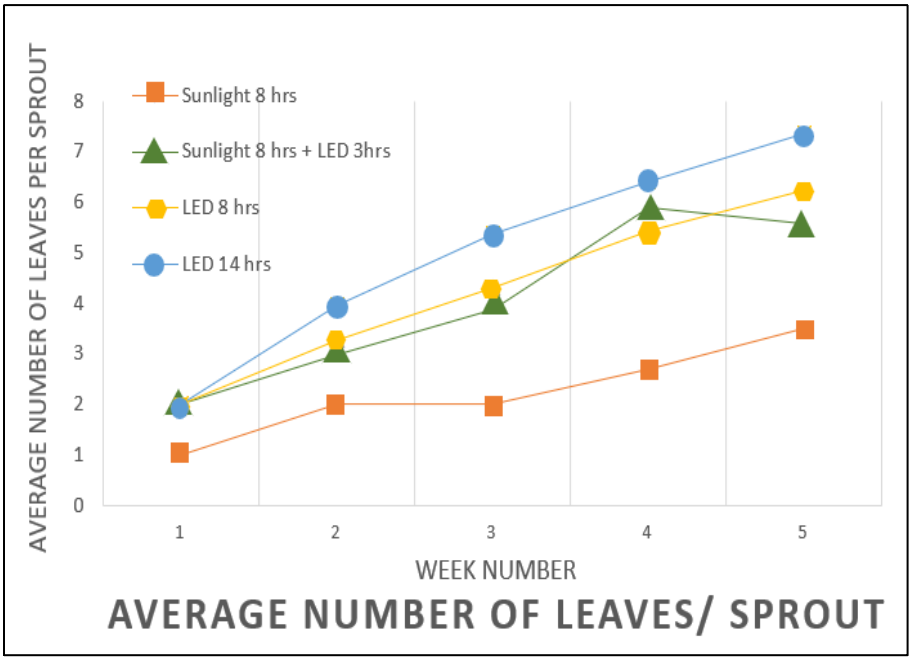
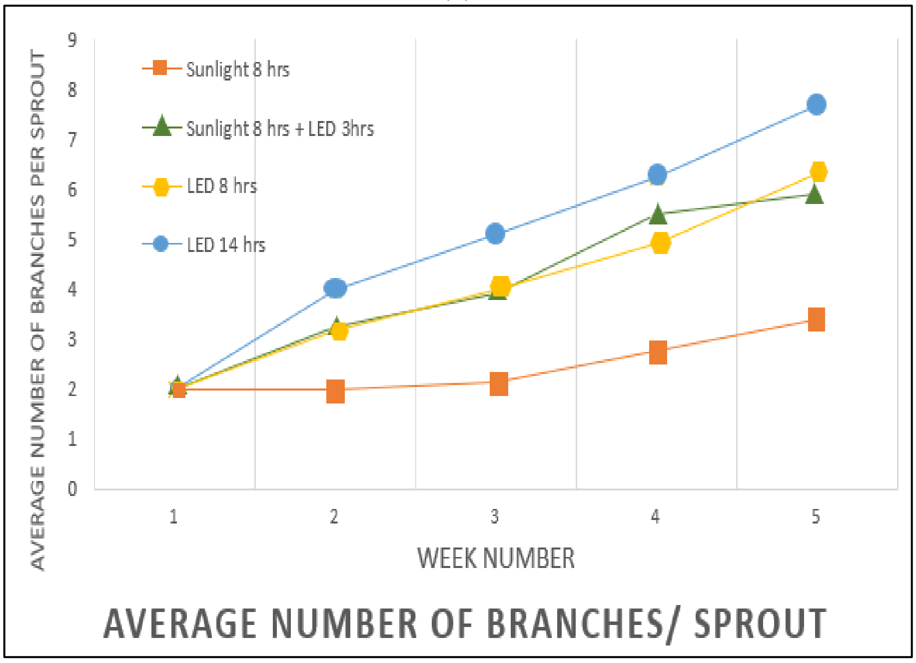


Fig. 2. Lettuce loose-leaf growth in week 5 for a different duration

In the following, the measured values were recorded and compiled into a line graph and shown in Figure 3 to Figure 5. In the data provided by Figure 3, it can be observed that both the average number of leaves and the average number of branches between week 1- week 5 are highest with the use of LED grow lights for 14 hours. However, the lowest values between week 1- week 5, for the aforementioned measurements were with the exposure of plants to only sunlight for 8 hours. The lettuce plant that was exposed to both sources of light (sunlight 8 hours, LED 3 hours) has shown a consistent increase in the average number of leaves/ sprouts and the average number of branches/ sprouts with its peak value of 5.9 cm (week 4) and 5.92 cm (week 5). But, for said exposure, there was a slight decline in the average number of leaves/ sprouts as the value for week 5 declined slightly with an average value of 5.57 cm leaves for each sprout. Hence, it can be concluded that the lettuce plants that were grown under LED grow lights have shown a consistent growth rate in the number of leaves and branches. This is also may be due to inconsistent weather as the plants that were exposed to sunlight do not receive a constant amount every day. Likewise, the utilization of LED growth lights provides a much more consistent energy source.



(a)

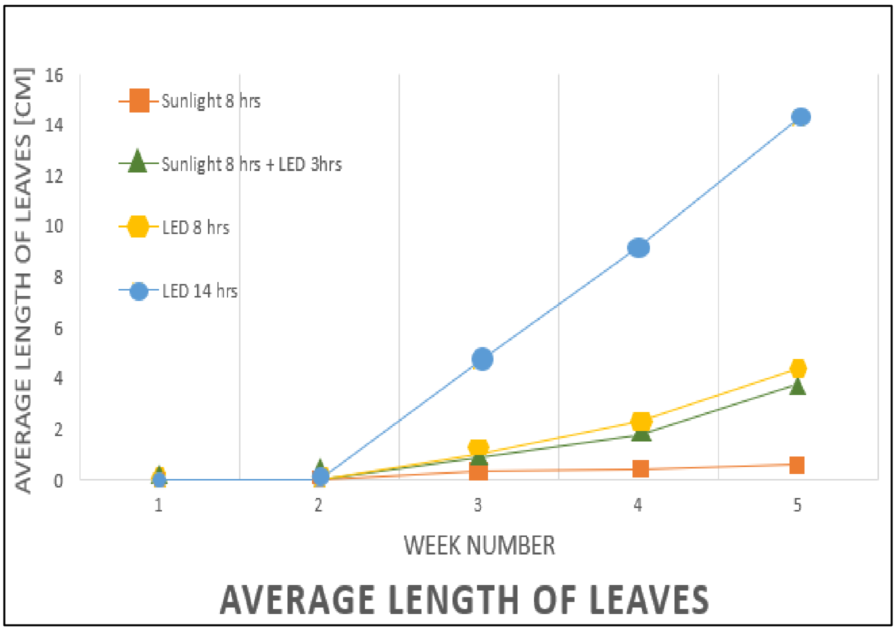


(b)

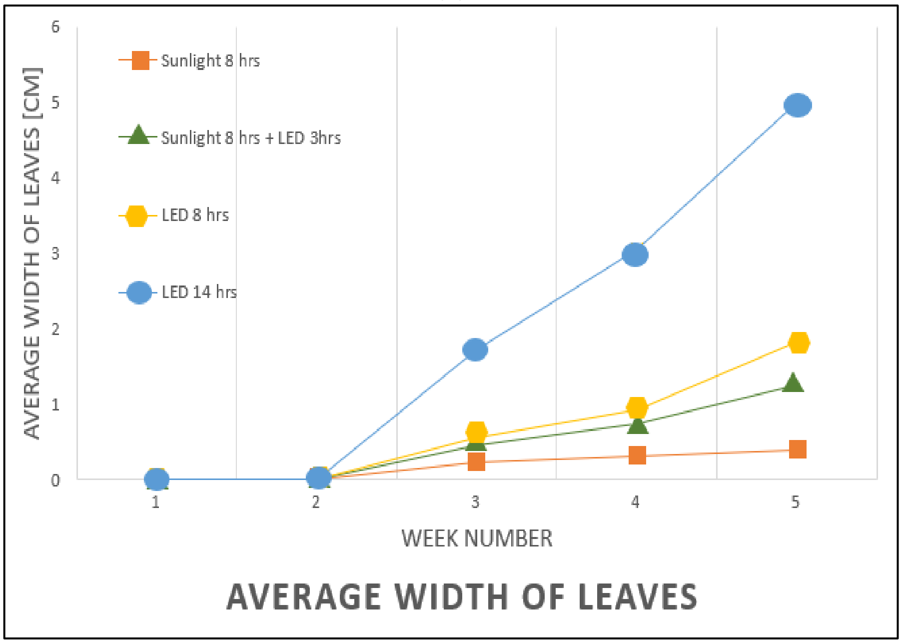
Fig. 3. (a) The average number of leaves/sprouts over 5 weeks, (b) The average number of branches/ sprouts over 5 weeks

For leaf measurements, the data are shown in Figure 4. From the data provided, it can be observed that both the average length and width of leaves show exponential growth with LED grow-light exposure of 14 hours. The growth rate for length and width decreases with less usage of LED grow-light, as such the average values highest with LED grow-light are 14 hours followed by LED-8 hours, a mixture of LED-3 hours of LED and 8 hours of sunlight, and finally sunlight exposure of 8 hours. For the length of the leaves, the highest rate was recorded at 14 hours of LED grow-light as such the values were 4.67 cm (week 3), 9.21 cm (week 4), and 14.24 cm (week 5). Similarly, the trend for the average width of the leaves with values of 1.71 cm (week 3), 3.04 cm (week 4), and 4.99 cm (week 5). On rack 3, the leaves that were observed by week 5 were mostly large and healthy.

However, some showed discolouration which may be due to excessive exposure to the LED lights. Those that were grown with the presence of sunlight had a much slower growth rate and smaller leaves. The plants that were grown in the sunlight did not receive enough energy, hence the length and width of leaves being shorter in both rack 1 and rack 2 in comparison with rack 3 and rack 4.



(a)



(b)

Fig. 4. (a) The average length of leaves over 5 weeks, (b) The average width of leaves over 5 weeks

Nonetheless, the length of stems was also evaluated as follows;

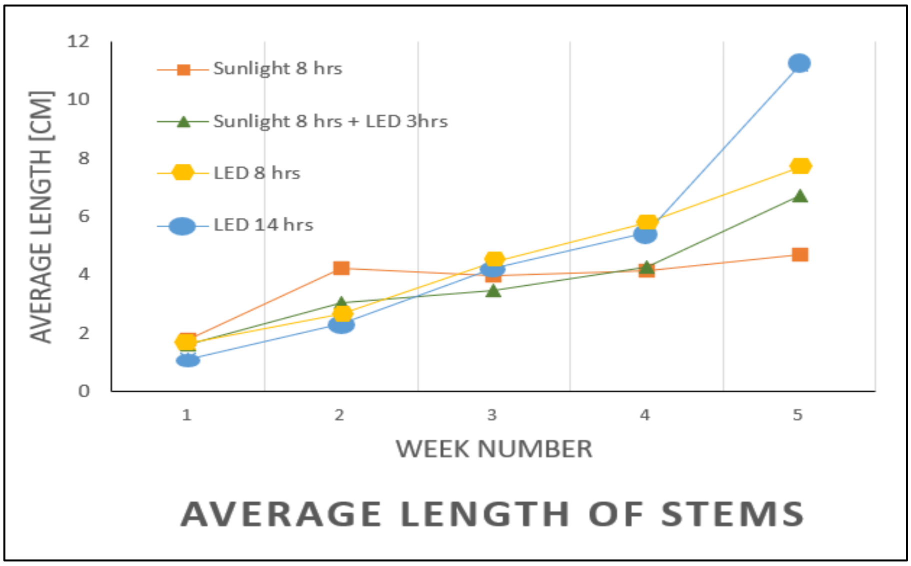


Fig. 5. The average length of stems over 5 weeks

From these data, it can be observed that at the early stage between week 1 and week 2, the plants that were grown under sunlight (8 hours) have shown a higher growth rate in comparison with the other environment. The elongation of the stem that is observed may be due to the hormones of the plants that are sent from the tip to the stem. The presence of light slows down the stem elongation at the beginning of the plant growth phase. However, from week 3 to week 5 it can be observed that those that were grown under LED grow-light exposure had a higher rate of stem elongation, with the highest average being recorded under LED grow-light (14 hours) with the value of 11.2 cm in week 5. The decline in the length of the stem for rack 1 (sunlight 8 hours) may be due to the insufficiency of light, which results in the plant mostly dying by the end of week 5. The stems that were observed under the presence of LED grow lights were also shown to have a thicker and healthier stem, whereas those grown under sunlight were mostly thin and frail. It can be summarised that a certain amount of darkness may increase the elongation of the stem, but the light source is very important for the plant to do photosynthesis and determine how long the stem must be grown [21].

4. Conclusions

Based on the results it can be seen that the growth of the loose-leaf lettuce is affected by the amount and period of exposure to the LED grow lights. Experiments, where the lettuce was provided for a longer period using LED grow lights, have a good influence on plant growth. Those that were only grown under sunlight were mostly wilted and unhealthy by week 5, hence for the utilization of indoor hydroponics systems, it is recommended that all of the racks should use LED grow lights. Out of the four treatments, the plants that were grown with LED grow lights for 14 hours (rack 3) showed a faster growth rate for width, length, and number of leaves. However, for the length of the stem, it can be concluded that at the early stage of plant growth, those that were grown with less light showed a higher rate of internode length. The basic effects of light are suggested to be modified by the different phases of the plant in terms of germinating, flowering and harvesting. The factor that may also influence such conditions may be the increased supply of raw materials as a consequence of early suppression of lower internodes and the beginning of photosynthesis.

There are some limitations of this study and incomplete data captured during the experiment such as light quality that measured through the daily light integral (DLI) is not taken. Research into optimal DLI for lettuce production is well established, as much work has been done examining differing light levels [20]. Furthermore, the measurement of the *photosynthetic photon flux density* (PPFD) and the total number of hours a plant is exposed to that PPFD to get the total quantity of photons per day, in units of mol $m^{-2}d^{-1}$ [20] is not being taken too. LEDs give growers more control over flavour and chemical profile of the plants. These factors need to be measured and take into account in the next continuous parts of this research project.

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