Study on The Effect of Different Light Intensity on Growth of Butterhead in Indoor Farming

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DECLARATION

I, at this moment, declare that the work embodied here is the result of my own study except for the excerpt as cited in the references.

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ABSTRACT

Artificial lights such as LEDs have been used successfully in indoor farming as an efficient light source for commercial plant cultivation. Artificial LED sources enable indoor farming operations with limited plant space and a focus on high productivity and quality to control the lighting environment. However, the different light intensities can have an effect on the plant's growth development and quality yield. To determine the optimal LED light setting for butterhead planting, an experiment was conducted using three different sets of LED lamps with varying light intensities and ratio colors. Hydroponic butterhead seedlings were grown under three different light treatment combinations, each with a different level of Photosynthetic Photon Flux Density (PPFD). LEDs with the same electrical power produce light of varying intensities, including Treatment 1 with a ratio of three red to one blue (58.4 mol m^{-2} s^{-1}), Treatment 2 with a ratio of two red to one white (84.01 mol m^{-2} s^{-1}), Treatment 3 with a ratio of two blue to one white (120.5 mol m^{-2} s^{-1}), and Control treatment with direct sunlight (123.41 mol m^{-2} s^{-1}). This study used a few parameters, including plant height, width, fresh weight, SPAD chlorophyll value, and nitrogen content. As a result, treatments utilizing white light perform well across all parameters measured. Treatment 2 produced the tallest plants, while Treatment 3 produced the widest leaves, and fresh plant weight resulted in increased growth and yield performance for butterhead plants when compared to the red-blue light treatment. While the Control treatment has the highest PPFD, the aid-specific light treatment may influence the growth of indoor plants. Even though in Treatment 3, the SPAD-chlorophyll values are highest in the presence of blue light treatment. These findings demonstrate that white LED light has a beneficial effect on butterhead growth and quality. They suggest that combining white LED light sources with red-blue light sources may be preferable for indoor butterhead farming.

Keywords: Light intensity, artificial light, Butterhead, indoor farming, SPAD-chlorophyll value

Kajian tentang Kesan Keamatan Cahaya Berbeza terhadap Pertumbuhan Butterhead dalam Pertanian Dalaman

ABSTRAK

Lampu buatan seperti LED telah berjaya digunakan dalam pertanian dalam bangunan sebagai sumber cahaya yang cekap untuk penanaman tumbuhan secara komersial. Sumber lampu LED tiruan membolehkan operasi pertanian dalaman dengan ruang tanaman yang terhad dapat memberi tumpuan kepada produktiviti dan kualiti yang tinggi untuk mengawal persekitaran pencahayaan. Walau bagaimanapun, keamatan cahaya yang berbeza boleh memberi kesan kepada perkembangan pertumbuhan tumbuhan dan hasil kualiti. Untuk menentukan tetapan cahaya LED yang optimum untuk penanaman butterhead, satu eksperimen telah dijalankan menggunakan tiga set lampu LED yang berbeza dengan keamatan cahaya dan warna nisbah yang berbeza-beza. Anak benih butterhead hidroponik ditanam di bawah tiga kombinasi rawatan cahaya yang berbeza, setiap satu dengan tahap Ketumpatan Fluks Fotosintetik (PPFD) yang berbeza. LED dengan kuasa elektrik yang sama menghasilkan cahaya dengan keamatan yang berbeza-beza, termasuk Rawatan 1 dengan nisbah tiga merah kepada satu biru (58.4 mol m^{-2} s^{-1}), Rawatan 2 dengan nisbah dua merah kepada satu putih (84.01 mol m^{-2} s^{-1}, Rawatan 3 dengan nisbah dua biru kepada satu putih (120.5 mol m^{-2} s^{-1}), dan Rawatan kawalan dengan cahaya matahari langsung (123.41 mol m^{-2} s^{-1}). Kajian ini menggunakan beberapa parameter, antaranya termasuk ketinggian tumbuhan, lebar, berat segar, nilai klorofil SPAD, dan kandungan nitrogen. Hasil keputusan menunjukkan rawatan yang menggunakan cahaya putih berprestasi baik merentas semua parameter yang diukur. Rawatan 2 menghasilkan tumbuhan yang paling tinggi, manakala Rawatan 3 menghasilkan daun yang paling lebar, dan berat segar tumbuhan berhasil meningkatkan pertumbuhan dan prestasi pengeluaran untuk penanaman butterhead jika dibandingkan dengan rawatan cahaya merah-biru. Walaupun rawatan Kawalan mempunyai PPFD tertinggi, namun rawatan cahaya khusus bantuan mungkin mempunyai kesan ke atas pertumbuhan tumbuhan dalaman. Malah dalam Rawatan 3, nilai SPAD-klorofil adalah tertinggi dengan kehadiran rawatan cahaya biru. Penemuan ini menunjukkan bahawa lampu LED putih mempunyai kesan yang baik terhadap pertumbuhan dan kualiti butterhead. Justeru itu, kajian ini mencadangkan bahawa menggabungkan sumber cahaya LED putih dengan sumber cahaya merah-biru mungkin lebih baik untuk penternakan butterhead dalaman.

Kata kunci: Keamatan cahaya, cahaya buatan, Butterhead, pertanian dalaman, nilai SPAD-klorofil

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% Percentage

°C Degree Celcius

LIST OF ABBREVIATION

Cm	Centimeter
Kg	Kilogram
PPFD	Photosynthetic Photon Flux Density
UMK	University Malaysia Kelantan
ANOVA	Analysis of Variance
SPSS	Statistical Package for the Social Science

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the next 50 years, fundamental changes are expected as the global population continues to rise rapidly, followed by increased global food demand. (Banerjee & Adenaeuer, 2014). Globally, approximately 38% of the total land area had been used for soil-based agriculture. This percentage represents approximately 800 million hectares of land. Additionally, 80% of the world's land suitable for growing crops is in use. Due to increasing food demand, additional arable land must be cultivated, and farming efforts must be stepped up. Indoor vertical farms are a novel solution that could potentially meet this need. (Despommier, 2013). Additionally, Despommier (2013) reported that cultivating agriculture in cities has piqued the interest of various academic and practical fields in recent years. Nowadays, indoor farming still faces technical and functional implementation challenges, but it has gained popularity in recent years. However, in countries such as China, South Korea, Japan, the United States, Singapore, and England, indoor farming are primarily focused on crop development and production (Sivamani, Bae, & Cho, 2013).

The food supply chain becomes chaotic during of the COVID-19 pandemic. The community is dealing with interconnected problems such as agriculture/safe and nutritious foods, the climate, community, and resource scarcity as a result of pandemics and the growing global population. As a result, food availability at the household and neighbourhood levels should be improve. Thus, home gardens will contribute to increased food security, nutritional value, and the health of the family members at home. Urban farming offers daily access to fresh vegetables and fruits by supplementing proteins, vitamins, and minerals, resulting in healthy and nutritious diets. (Galhena, 2013). Urban farming can be implemented in many forms depending on the level of expertise and with various farming techniques. For example, planting vegetables in indoor using hydroponic system, which is crops are fed with nutrients through water, eliminating the needs of the soil.

In comparison to natural sunlight, which varies in intensity, duration, and spectral composition throughout the day and season, light intensity in indoor farming is typically maintained constant. Light intensity and photoperiod are two critical light conditions for controlling plant growth, productivity, and nutritional values. (Dou & Niu, 2018). Due to their numerous advantages over traditionally protected horticulture, indoor farming has recently become more common in the cultivation and processing of vegetable seedlings, herbs, and medicinal plants. According to Kozai and Niu (2016), "indoor farming with artificial lighting, such as Plant Factory with Artificial Lighting (PFAL), can be classified into two groups based on the source of light: (1) artificial light alone and (2) artificial light and (supplemental) solar light." As Kozai et al. (2016) statement, these systems aim to the minimum release of environmental pollutants, improve plant quality, and increase output yields with high-value production.

As a result, this study examined the combined effects of light intensity on the growth and development of butterhead seedlings grown indoors. This study attempted to uncover the complex interaction about the light intensity and how different wavelengths affect the growth of vegetables to gain a better growing technique that is suitable for the natures and preferences for butterhead seedlings in terms of environmental conditions. The specific light intensity and wavelength of light can be identified for optimal growth of targeted vegetable crops using the correct method concerning how the quality of crop yield in PFAL can be maximized.

1.2 Problem Statement

Many studies have been conducted on the impact of photosynthetic photon flux density (PPFD) or as known as light intensity, on plant growth in indoor farming systems. Few studies, however, have looked into the effects of these factors on plant development. Furthermore, most research concentrate solely on the variations between individual treatment conditions rather than looking at the overall pattern in plant responses to various light intensity influences (Dou & Niu, 2020).

Since each plant species has its preference for their need to light intensity, it becomes a problem for people especially farmers, to set a specific light requirement for their growth of plants, especially vegetables such as butterhead. So, with the help from the result of this experiment, it will give people more knowledge and a better understanding of plant characteristics and how their growth and quality will respond to the light intensity that can be used by farmers to improve their yield.

1.3 Hypothesis Statement

Null hypothesis Ho: High light intensity has no significant effect on the growth and quality of butterheads.

Alternative hypothesis H1: High light intensity have a significant effect on the growth and quality of butterhead.

1.4 Objective of The Study

The main objective of this experiment is to study the effect of light intensity on the growth and quality of vegetable crops, which is butterhead. This study can help people especially farmers and cities people that use the indoor farming systems to fulfill their vegetable's need for proper light intensity value. Another objective of this study is written below:

1. To investigate and identify the optimal light intensity for butterhead plants.
2. To measure the morphological growth of butterheads that are affected by different intensities.
3. To study the yield of vegetables (butterhead) with the optimal light intensity

1.5 Significance of The Study

Undeniably, plant factories that use artificial light available within Malaysia were still new. The expensive cost of operation for plant factories lead to low interest among Malaysians to involve in this indoor farming technique. This was because these commercial indoor farming use high electrical energy is included lighting and also environment-controlled devices such as air conditioners and heaters to make sure crops get optimal temperature for their efficient growth. At least, this new knowledge and information about the optimal light intensity derived from this experiment can encourage people that want to involve in the indoor farming industry hence reducing the cost of electrical bills with the increasing of crop yield quality and quantity.

In this experiment, the method use to identify the optimal and accurate light intensity for butterhead plants was a crucial step in identifying the optimal of life-saving energy to plant vegetables through indoor farming whilst producing high quality with higher yield thus reducing the value of light energy needed for plants to grow with high quality and reduce the electrical cost.

1.6 Limitation Of Study

Due to a lack of laboratory facilities for the experiment, there are inconsistencies in the precision of the results that could be impacting the experiment data eligibility and availability. From previous study, researchers used growth chamber to help them easily maintained and controlled the air temperature, relative humidity and also CO_2 concentration to enhance their plant growth. In addition, an adjustable rack is recommended for this study. It is because every plant grow stage have their own distance from light source in indoor farming.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Farming in Malaysia

In countries like Malaysia, indoor farming also solves food security by ensuring that city dwellers have access to food that is sufficiently nutritious, healthy, suitable, and cost-effective. Indoor farming can also be used as a means of addressing the subsistence practices of urban households to meet these goals. Several government institutes and organizations, including the Minister of Agriculture and Food Industry (MAFI), have started to promote local citizens to engage in modern agricultural activities such as indoor farming. Given the effect of indoor farming on urban food security and the growing concern from a variety of agencies across the world, determining how indoor farming contributes to overall food security and the provision of a nutritious diet becomes critical.

The growth of Malaysia's vegetable sector has been increasing year after year. According to the Department of Agriculture (DOA) Malaysia's 2018 statistics, lettuce ranked tenth in terms of highest hectare for ten different types of vegetables and cash crops. In 2017, lettuce production is 4, 358.27 metric tons. (Hanizah, 2021) The lettuce harvest area has been increased from 2552 hectares in 2017 to 3325 hectares in 2019 (Hanizah, 2021). This demonstrates that lettuce production continues to rise year after year due to increased demand and that this trend will continue in the coming years. If the technology were used, lettuce yield could be greatly improved.

2.2 Indoor Farming

Indoor farming is a way of farming and growing crops entirely in an indoor place (Stein E.W, 2021). Furthermore, indoor farming is becoming increasingly common in major cities where large plots of land for growing, and farming are scarce. Indoor agriculture is being used extensively to augment local food supplies and to provide fresh food to communities in large cities. Not all indoor farms, however, are built on this scale. Indoor farms as small as a basement can be constructed and used by a single gardener to supply their home with fresh fruit and vegetables.

Most indoor farming uses artificial light and hydroponic systems to grow their plant and provide nutrients for their plants. There are many varieties of indoor farms that have been used in recent years, depending on the condition and suitability, including greenhouse farms, vertical farms, and Controlled Environment Agriculture (CEA) (Goodman, Minner, 2019). Greenhouses have a lot in common: they are covered in materials like glass to let in natural light, they have climate management and irrigation systems, and they all grow on one basis. Greenhouses, which are typically used to grow edible plants, were initially built to grow tomatoes, but are now used to grow microgreens, lettuces, herbs, and a variety of other fresh produce. Indoor vertical farms, also known as indoor farms, vertical farms, or plant factories, are another way of growing fresh vegetables and other products. Vertical farms for growing leafy greens are also in their early stages of growth. Plants are cultivated completely indoors using LED lights in these farms. Farmers will now save money by supplying crops with the right wavelengths of light to maximize the development of plants. Thanks to the introduction of powerful LED lighting technologies.

Many indoor farmers prefer getting more control over the climate when growing indoors rather than when using conventional farming methods. When growing crops exclusively indoors, the farmer has complete control over the amount of light, nutrition, and moisture. Plants of all kinds may be grown indoors, but the most common are fruits, berries, and herbs. Crop plants such as lettuce, tomatoes, peppers, and herbs are among the most common indoor plants.

2.3 Plant Growth Under Different Light Wavelengths

Light is electromagnetic radiation of both visible and invisible wavelengths. The force is stronger, the wavelength is shorter. The wavelength of visible light is between 380 and 780 nm. Plants need visible light since it approximately corresponds to "photosynthetically active radiation" (PAR) which is 400-700 nm (Dou & Niu, 2018). However, only electric light is used in indoor farming industries such as Plant Factory.

Early studies with light-emitting diodes (LEDs) proved that red light (600-700 nm) is the most efficient at driving photosynthesis but, supplementation with blue light (400-500 nm) is required for normal plant growth (Mainard, 2016). Other than that, far-red radiation (700-780 nm) will decrease efficiency at driving photosynthesis, and radiation beyond this wavelength is hard to absorb by leaves (Mainard, 2016). But, not all visible light radiation is absorbed with the same efficiency by leaves. In addition, radiation outside photosynthetically active radiation (PAR) does not drive photosynthesis but plays some role in plant morphogenesis and metabolism (Tello, 2018). Frigo strawberry plants produce more fruits with higher soluble sugar content, potato plants produce more tubers, and cucumber, tomato, pepper, radish, lettuce, and potato plants grow more compact when exposed to blue light.

Table 2.1 Wave properties of light and their importance

Type of Light	Wavelength (nm)	Benefits
Ultraviolet	100-380	
UV-C	100-280	Disinfecting
UV-B	280-320	Disinfecting Photomorphogenesis (e.g., sunburn, inhibition of stem elongation), plant secondary metabolite production, disorder, and damage
UV-A	320-380	Photomorphogenesis (e.g., sunburn, inhibition of stem elongation), plant secondary metabolite production, photoreactivation
Visible Photosynthetically active Physiologically active	380-780 400-700 300-800	Photosynthesis, photomorphogenesis (e.g., seed germination, seedling de-etiolation, shade avoidance response, hypocotyl and root phototropism, circadian oscillation, reproduction response), and plant secondary metabolite production
	spectrum, between red and infrared light)	avoidance response, and reproduction response), photosynthesis (excitation of photosystem I)
Far-red	700-800(at the extreme red end of the visible	Photomorphogenesis (e.g., seed germination, seedling de-etiolation, shade
Near-infrared	780-2500	Heat
Infrared	2500+	Heat

Fujiwara (2013) stated that three basic types of grow lights available are usually used in indoor urban farming nowadays: (1) Fluorescent grow lights, (2) High-intensity discharge (HID) lamps, and (3) Light-emitting diodes (LED) lights.

2.4 Plant Responses To Light Environment

Photosynthesis is very important to plant growth and food development. Chloroplasts found in the leaves can help plants to make photosynthesis process. The main process for photosynthesis taking place was the chloroplast in the mesophyll cells of the leaves (Yamori, 2014). Three primary processes of photosynthesis are light absorption by photosynthetic pigments, electron transport and bioenergetics, and carbon fixation and metabolism (Yamori, 2014).

The photosynthetic system undergoes a series of energy-transfer reactions inside the chloroplast thylakoid membranes to transform the transient energy of light to stable chemical energy (Yamori, 2014). In higher plants, the process begins with the capture of light through a network of antennae containing two forms of photosynthesis pigments, chlorophylls, and carotenoids. The predominant pigment is chlorophyll, which absorbs significant amounts of red and blue light. Carotenoids are pigments that strongly absorb blue light, allowing chloroplasts to capture a greater portion of light energy. Chlorophylls and carotenoids in isolation emit green light. However, intact chloroplasts and entire leaves absorb a significant portion of the visible light spectrum, just like a green light.

Light scattering is an optical phenomenon that has an effect on the absorption properties of a leaf on a global scale. Light scattering occurs primarily in leaves as a result of reflection between intercellular air spaces and cells (Evans et al., 2004). Red and blue light are absorbed mostly on the illuminated side of a leaf, while green light penetrates deeper into the leaf, increasing its chances of absorption due to its longer path duration and numerous reflections at cell wall/air interfaces (Terashima et al., 2009). If an action spectrum explicitly shows that red light is more effective for photosynthesis, leaves use the majority of light in the photosynthetically active region of the spectrum (400-700 nm).

Understanding how photosynthetic apparatus perform for light absorption and their effect under the different wavelengths of light will help to improve knowledge on how plants react to light and help in the selection of lighting solutions for indoor farming. Other than that, the pandemic has increased the importance of indoor farming because it ensures food security, which aids the country in meeting crop demand. Since this outbreak has a significant impact on people's health, companies involved in indoor farming are implementing steps to help them grow crops safely. Furthermore, the advancement of aquaponics and hydroponics has increased food security. As a result, the introduction of indoor farming has improved food security during a pandemic crisis.

2.5 Light Emitting Diodes

In comparison to incandescent, fluorescent, and high-intensity discharge (HID) lamps, LEDs offer several advantages. They are robust, produce a constant output, are long-lasting, are compact and lightweight, switch on instantly, and allow for simple control of the light output (Fujiwara, 2013). Additionally, a light source comprised of several color LEDs may be used to monitor the spectral distribution of emitted light.

A light-emitting diode (LED) is a type of semiconductor diode that is formed when p- and n-type materials come into contact (Goto, 2016). By applying a sufficiently high forward voltage to the diode, holes (with a positive electrical charge) in the p-type material side and electrons (with a negative electrical charge) in the n-type material side can be recombined. When a hole and an electron recombine, a photon with the same energy as the electron's transition energy is formed.

A major but lesser-known benefit of using LEDs as a light source for indoor farming with artificial light is that, as compared to standard lamps, LEDs provide greater flexibility in producing a variety of light environments. For instance, a light source consisting of different LEDs of varying peak wavelengths. In the Netherlands, a commercial lettuce seedling processing facility already uses an LED module combining blue, red, and far-red LEDs. A multicolor LED module that contains green, violet, or ultraviolet LEDs in addition to blue and red LEDs have been used in a Plant Factory Artificial Light (PFAL) and it has been demonstrated to improve plant growth and/or nutritional and functional ingredients beneficial to human health.

2.6 Summary

In conclusion, indoor farming in Malaysia should be applied efficiently to improve the quality and quantity of food production. Furthermore, the rising cost of food production, manufacturing, and distribution is putting upward pressure on urban residents' living costs. As a result, indoor farming, which is part of the urban agriculture farming system, may be one of the ways to meet the demand for healthy food yields. This farming technique can be used not only for large-scale cultivation but it can also be used as a hobby to live a healthier lifestyle. Knowing how light wavelength and the perfect combination of LED colors affects plant growth is critical for improving biomass productivity and increasing bioactive secondary metabolite concentrations in butterhead vegetables in an indoor farming system.

CHAPTER 3

MATERIALS AND METHOD

3.1 Experiment Design

This experiment would use a randomized complete blocked design (RCBD). By using 8 mini-DIY hydroponic sets, butterhead was cultured in the hydroponic set under four different light intensities. It was mean that each treatment which was a combination of light were used once for every block represented by the butterhead. The hydroponic set consists of 5 holes. The culture was provided with four different light intensities through a combination of different light colors which were 3 red 1 blue, 2 red 1 white, and 2 blue 1 white. One more treatment were put at a place that received a source of sunlight. The light intensity of the led lamps were measured for each treatment including the light intensity for the sunlight source. It was measured by using pro's kit mt-4617 led light intensity meter. The photoperiod was 16 h per day. This experiment was held in an air conditioner room. The vegetables would let grow until it reaches their mature state to harvest. After that, the data collection could be done to produce results for future used

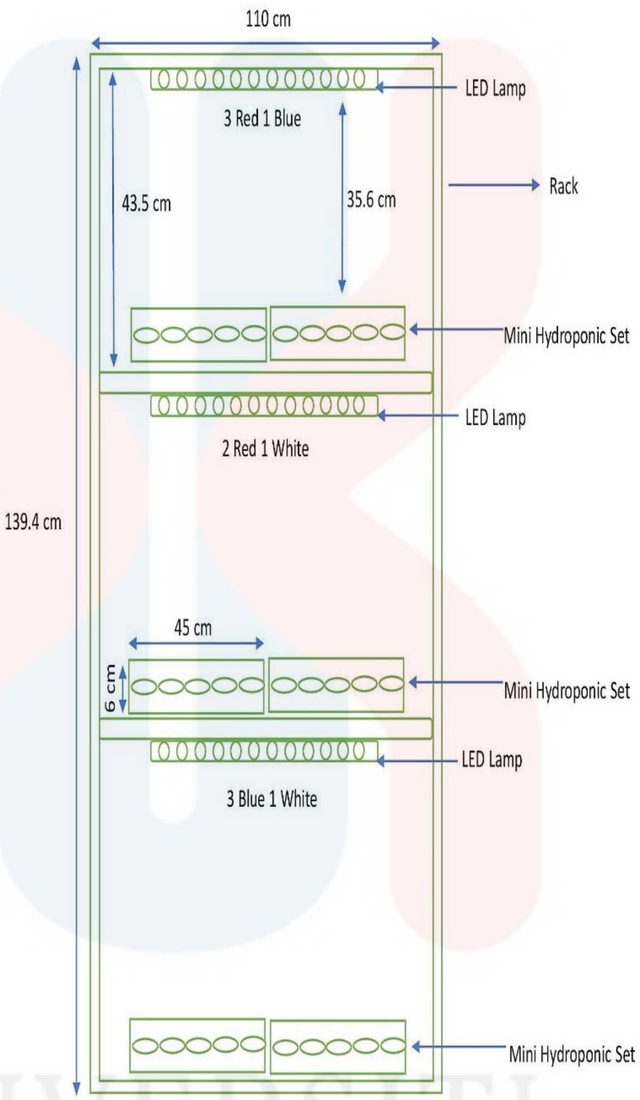

Figure 3.1 Shows the Hydroponic Rack system

Table 3.1 Samples of Vegetable Crops Under Four Different Treatment

Vegetable Crops	Treatment 1	Light Treatment	Number of Replication
Butterhead	1	3 Red 1 Blue	10
	2	2 Red 1 White	10
	3	2 Blue 1 White	10
	Control	Under Source of Sunlight	10

3.2 Plant Material

Butterhead plants were used for this experiment to study the effect of different light intensities on its growth. First of all, the seeds for butterheads were bought from the shopee which was from baba smart grew company. Butterhead lettuce was a cool-weather crop. This type of crop could not be planted in hot weather areas. In the Jeli market, it was not much sold in the wet market for this type of vegetables. If people wanted to eat this vegetable, they needed to go to the Pantai Timur to buy this vegetable

Rock wool was used to sow the plant's seeds. First, rock wool needed must be irrigated with tapped water. Then, the seed for butterhead lettuce were sown on rock wool. For butterhead seedlings, the seedlings were transplanting to hydroponic pot 3 days after the seeds started to sprout. While waiting for the seed to sprout, the seed were put in dark plastic that was not exposed to sunlight

3.3 Culture System

This study on plant growth using artificial light was carried out in an indoor place that does not expose to direct sunlight. The room that had an air conditioner was used to make sure the culture crop would be got a suitable temperature for their growth. The temperature was set to 21˚c and the pH and EC values of cultured solution were measured every 24 hours. This indoor farming used a mini hydroponic set to grow the vegetable crops. The butterhead seedlings were provided with AB nutrient solution for plant source of nutrient. A rack that was provided with light-emitting diodes with different colors and light intensities were set up for the crops

3.4 Data Collection

The fresh weight of the leafy components, the area of the largest leaf, and the plant width are all growth indexes that were measured. The fresh weight was calculated immediately after the plants were removed from the hydroponic pot. The measurement of the leaf and the plant width was measured using a ruler in a centimeter (cm) unit.

Chlorophyll and leaf nitrogen content were analysed for the quality indexes. The concentration of chlorophyll in the leaf were determined using a SPAD chlorophyll meter (SPAD502Plus, Konica Minolta Sensing Inc., Osaka, Japan). SPAD meter was provided by the UMK laboratory. Butterhead leaf were used to measure the average chlorophyll content in the leaf by using the SPAD meter.

For nitrogen content, the Kjeldahl method was used to measure the levelled organic nitrogen in the vegetable plant. Firstly, the plant samples needed to digest used concentrated sulfuric acid that were digested by heat. The nitrogen would dissolve into ammonia and react with the sulphuric acid and ammonium sulfate were produced. The solution was subjected to steam distillation under alkaline conditions and the distilled under alkaline conditions and the distilled ammonia was absorbed with a known amount of sulphuric acid. The total nitrogen was determined by titration.

3.5 Statistical Analysis

Statistical analysis was performed using the SPSS 26.0 (IBM, Inc., Chicago, IL, USA). All data were analyzed for significance by an analysis of variance (ANOVA) followed by the least significant difference Tukey's test for mean separation at the $p < 0.05$ (n=10). The graph for growth performance was performed using Microsoft Excel 365 software (Microsoft Corporation, Redmond, WA, USA).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Growth Performance analysis of Butterhead under the different light combination

Based on the study that has been done, all plant for each treatment keeps growing day by day indoor using the hydroponic farming system under different light combination. However, continued observation showed significant differences in the growth performance of the butterhead plant for each treatment. Figure 4.1 showed all three treatments, with one control growing differently under different light sources. All growth performance data was taken during the growth stage started from the day after transplanting until harvesting day. Each light treatment has its own light intensity value measured using a lux meter then converted into a PPFD unit, which is μ mol m^{-2} s^{-1}. Table 4.1 shows the mean PPFD value for each treatment that was taken. Table 4.1 illustrates that between groups and within groups are significant which denotes a sig. of 0.000 meaning that it is significant at $p<0.05$. But the mean for treatment 3 and control treatment does not show significant differences between the group. It concludes that light treatment for treatment 3 was suitable to replace sunlight sources in indoor farming. The growth performance data for treatment include plant height, leaf width, plant fresh weight, and SPAD meter reading.

Table 4.1: Mean PPFD value for each treatment.

Treatment	Light Source	PPFD (μ mol m^{-2} s^{-1})
Treatment 1	R: B (3:1)	58.40^{c}
Treatment 2	R: W (2:1)	84.01^{b}
Treatment 3	B: W (2:1)	120.50^{a}
Control	Direct sunlight	123.41^{a}

*Means separation in each column followed by the same letter are not significantly different at p=0.05

4.1.1 Plant Height

Figure 4.1.1 shows the plant height measurement taken from the fourth day after transplanting until day forty-four for each sample in every treatment. Based on the line graph shown in figure 4.1.1, plant height for butterheads does not directly affect by the high PPFD. As shown in figure 4.1.1, Treatment 2 shows higher plant height measurement followed by Control treatment and Treatment 1. In contrast, Treatment 3 was the lowest among all treatments. Whilst Treatment 2, red light wavelength had directly affected the plant height. The present study found numerous plants are grown under red light, such as those grown indoors with red LEDs, exhibit a stretched, elongated appearance, and grow tall (Runkle, 2021). White LED light has also been reported to increase growth and the content of phenolic compounds in lettuce in the previous study (Son, Jeon & Oh, 2016). Even control treatment and Treatment 3 has the highest light intensity, the presence of red LED light in Treatment 2 keeps enhancing the plant height. Since Treatment 1 has low light intensity compared to Treatment 2 and Control, the plant height for this treatment becomes lower than both. But still, the presence of red light in Treatment 1 makes the butterhead grow taller than in Treatment 3.

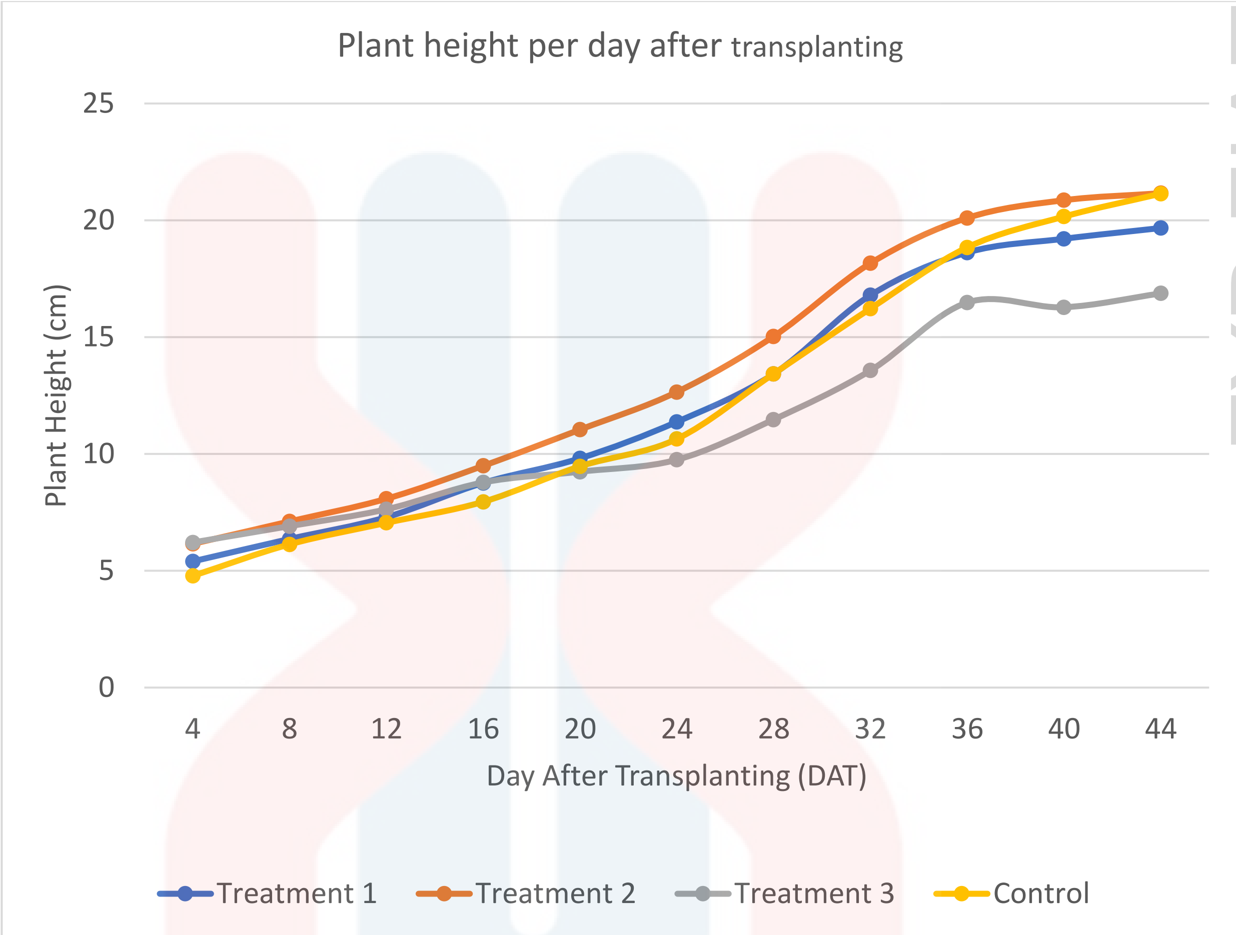

Figure 4.1.1: Plant height of butterhead crops

4.1.2 Leaf Width

Figure 4.1.2 shows leaf width measurement was taken from the fourth day after transplanting until day forty-four for each sample in every treatment. In this study, leaf width played a significant role in showing differentiation between the effect of light intensity on the butterhead leaf. A specific light wavelength to promote butterhead leaf growth also shows substantial differences between each treatment. As shown in Figure 4.1.2, the leaf width for Treatment 3 was the highest compared to the Control treatment. Even though the Control treatment had higher light intensity, the presence of blue and white light wavelength in Treatment 3 affected the leaf width for butterhead. The differences in spectral wavelengths and compositions among red, blue, and white treatments significantly affected the growth of butterheads (Loan Nguyen, Man Cho, Yul Lee & Yong Cha, 2021). Moreover, Loan Nguyen et al. (2021) also mentioned that the increased leaf area and leaf number of butterhead lettuce in treatments with white light contributed to the higher biomass of these cultivars. Similarly, Han et al. (2017) discovered that lettuce grown under broad white or narrow white LEDs had a greater leaf area and total fresh weight than lettuce grown under red plus blue LEDs. Other than that, the factor that makes Treatment 1 leaf width stunted was due to the low light intensity of the light treatment.

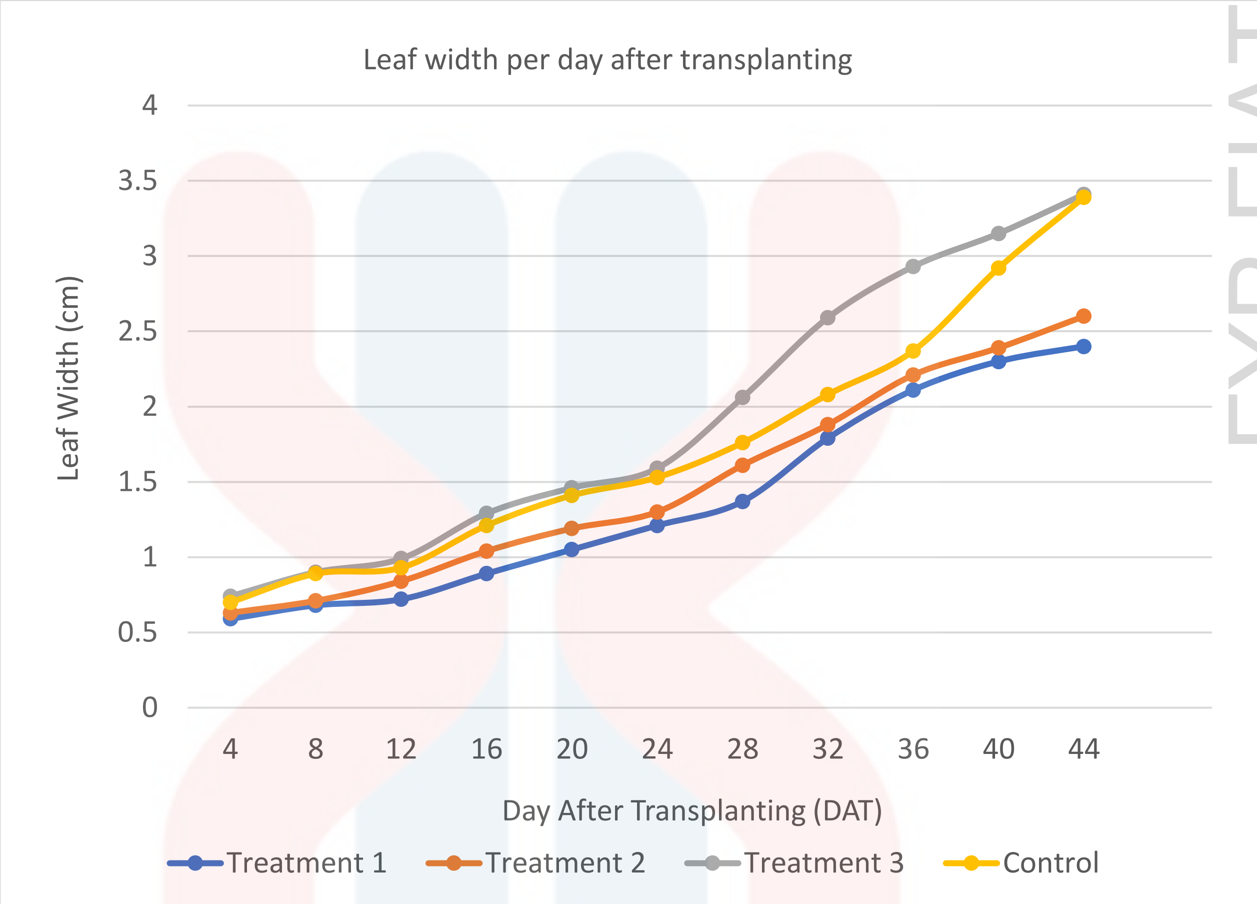

Figure 4.1.2: Leaf width of butterhead crops

4.1.3 Plant Fresh Weight

Figure 4.1.3 shows the average plant fresh weight for butterhead crops. The data for plant fresh weight was taken after butterhead was harvested. The weight for each butterhead sample was weighed accordingly. Then, the average weight for each sample was calculated. The increasing light intensity significantly affects the plant's fresh weight from Treatment 1 until Treatment 3. Based on the previous study by Loan Nguyen, et al.

(2021), the proportion of shoot fresh weight and PPFD was higher in all white treatments, especially in the treatments that had white light. This finding also can be related to the present study. Hence proved that increasing light intensity had positively impacted the butterhead plant's fresh weight. Besides, the high light intensity for control treatment does not guarantee high plant fresh weight for this treatment. The presence of a light environment in Treatment 3 enhanced the fresh plant weight for this study.

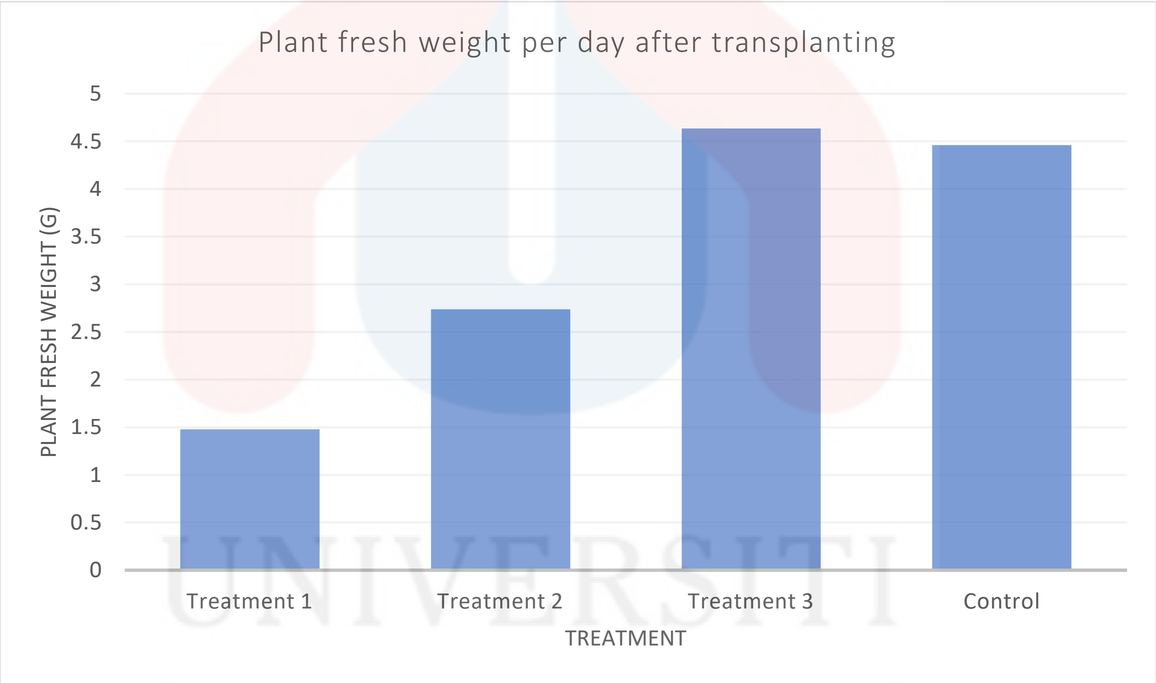

Figure 4.1.3: Average plant fresh weight (g) for butterhead crops

4.1.4 SPAD Meter by week

The data for SPAD-chlorophyll values were taken three times a week. The SPAD-chlorophyll values were observed as the highest in Treatment 3 from Week 3 until the first data for Week 6. In the second data for Week 6, the SPAD-chlorophyll values for Treatment 2 increased and making it the highest compared to all treatments. But the data for Treatment 2 in the next days for week 6 decrease and make Treatment 3 became the highest SPAD-chlorophyll values among all treatments. Numerous studies have established the beneficial effects of red LEDs on biomass accumulation and stem elongation, as well as the beneficial effects of blue LEDs on chlorophyll production, stomata opening, and photosynthesis (Wang, 2020). The present study proved that the SPAD-chlorophyll values for Treatment 3 which has a blue LED light had the highest value of SPAD chlorophyll values compared to other treatments throughout the planting period.

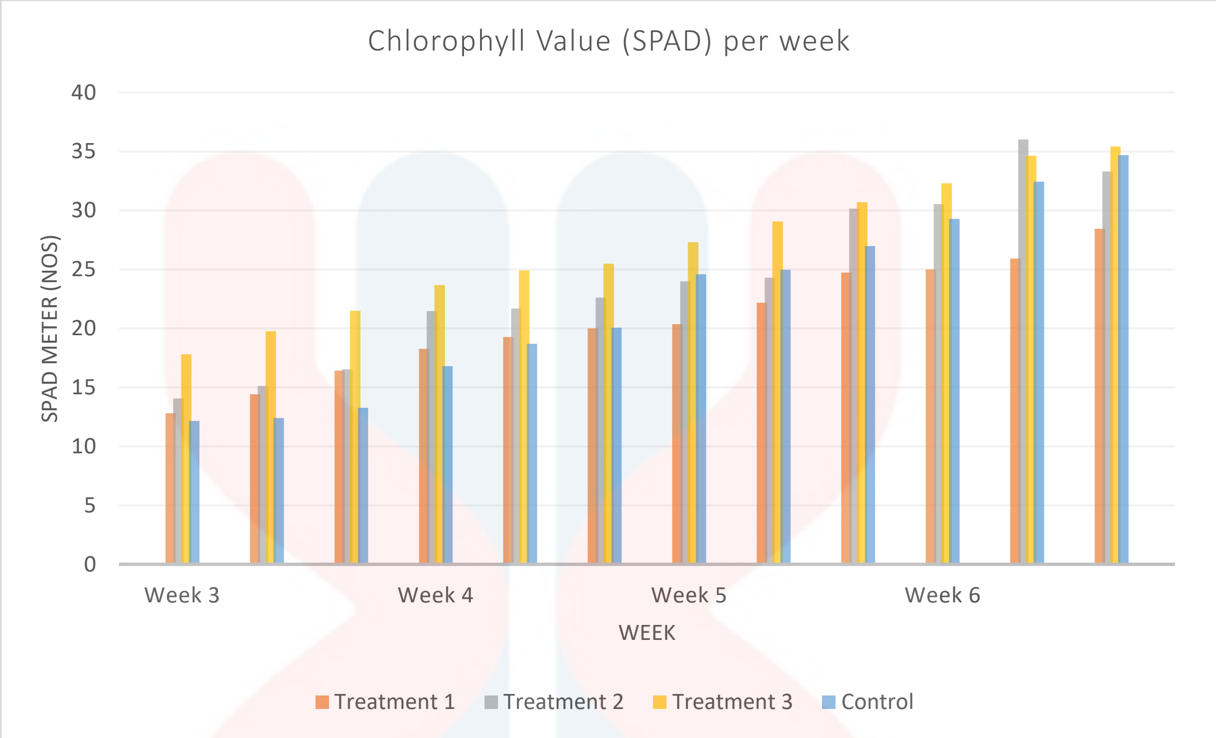

Figure 4.1.4: SPAD meter for butterhead crops for Treatment 1 until Control treatment.

4.1.5 pH reading for butterhead

The pH value may vary according to the growth stage of various plants. It is necessary to monitor the pH of the nutrient solution in order to detect changes in the reading. The pH changes indicate the availability of nutrients in the solution. The pH level should be adjusted according to the plant's growth stage, with butterhead preferring a pH range of 5 to 6.5. (Resh, 2013).

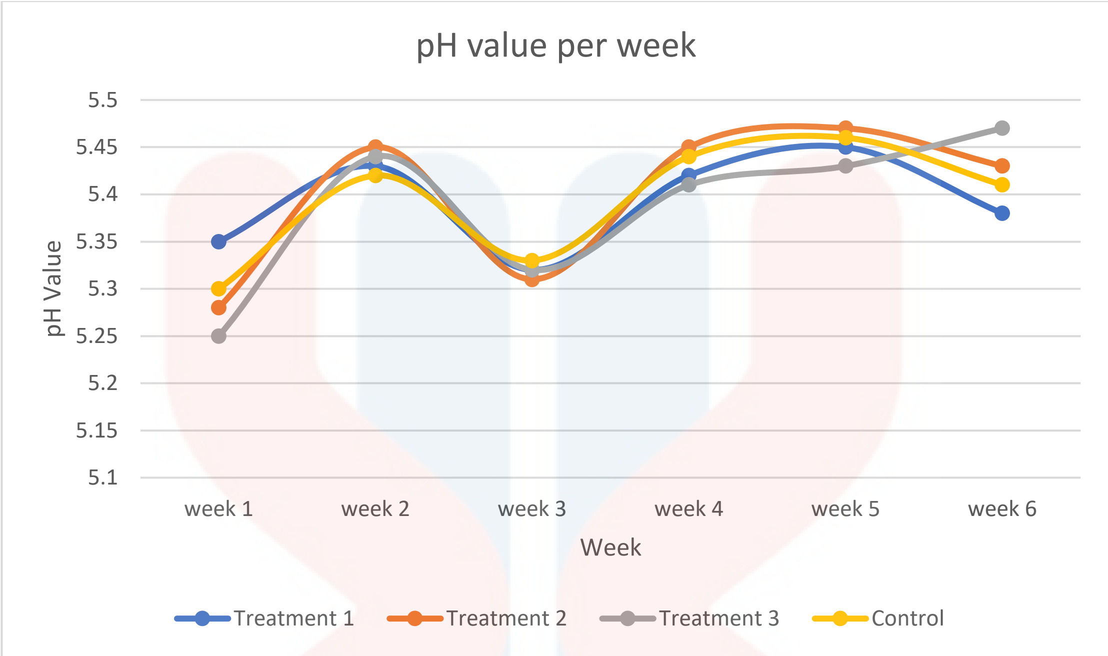

Figure 4.1.5: pH value for butterhead crops for Treatment 1 until Control treatment.

4.1.6 EC Meter reading for butterhead

The EC value will vary depending on the type of plant and its stage of growth. To obtain an accurate reading, the EC meter was kept stable at 23°C below the ambient temperature. The EC value should be between 1.2 and 1.8 mS/m for lettuce (Singh, 2017). Every day, the EC level is kept within the acceptable range for lettuce.

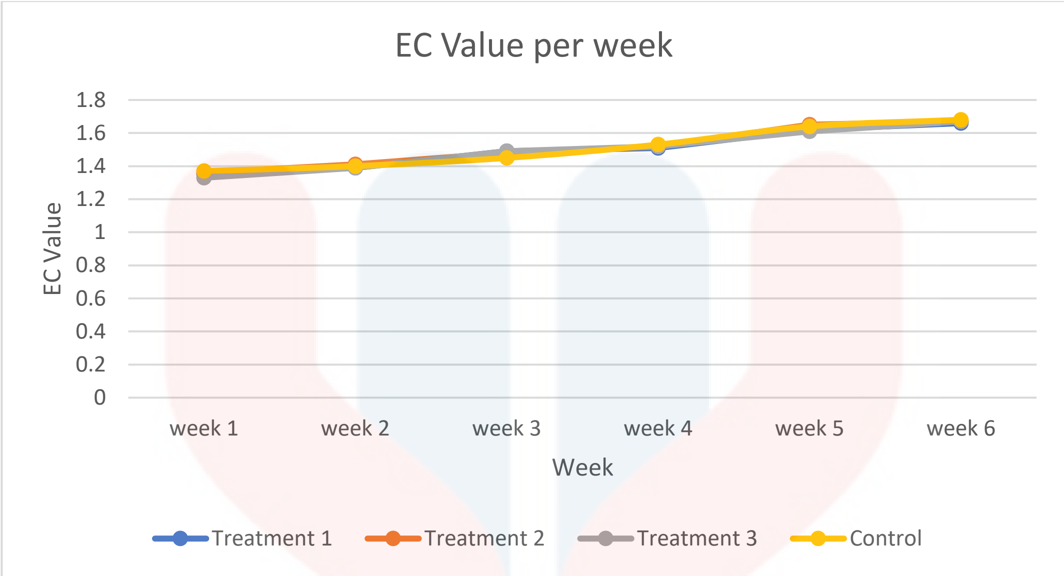

Figure 4.1.6: EC value for butterhead crops for Treatment 1 until Control treatment.

4.1.7 Effect of Light intensity on Butterhead Growth

Light intensity, or PPFD, is a well-known critical factor in plant growth and development, as increased photosynthesis results in increased plant biomass. In contrast, low light intensity typically results in photoinhibition and affects plant photomorphogenesis (Dou & Niu, 2020) . Despite this, the differences in the spectral wavelengths and compositions of red, blue, and white light treatments significantly affected butterhead plant growth performance. Different light treatments, including red, blue, and white light, significantly affected butterhead growth, regardless of the light intensity used. Additionally, the presence of white light treatment aided in the development of butterhead in Treatments 2 and 3 had brought specific growth impact for butterhead cultivar. According to a previous study by Loan Nguyen, et al.(2021), white light with the same electrical power produced approximately 24~32 percent more PPFD than red and blue treatment, which contributed to the growth of butterhead cultivars. Sago (2016) reported that butterhead lettuce frequently developed tip burn when exposed to high light intensities ranging from 150 to 300 μ mol m^{-2} s^{-1}, which may have been caused by a calcium deficiency in the inner leaves. The present study's results indicate that no tip burn occurred for butterhead cultivars because the total light intensity for each treatment was less than 150 μ mol m^{-2} s^{-1}. In short, is it true that light intensity can truly affect plant growth, but adding the right light treatment for plants that grow in indoor farming can increase the quality of plant growth.

4.2 Yield Performance analysis of Butterhead under the different light intensity

Yield performance for butterhead has been measured on the last day after the plant was harvested. The parameters for plant yield performance analysis were mean plant height, mean leaf width, mean fresh weight, and mean SPAD chlorophyll values for every week starting from week 3 until week 6.

4.2.1 Plant height, leaf width, and fresh weight analysis

The mean analysis for parameters such as plant height, leaf width, and plant fresh weight for each treatment with different light intensity and different light treatment was summarized as in table 4.2.1.

For plant height, the result shows a significant difference for the mean on the plant height as in table 4.2.1. There was a significant value of 0.00 meaning that it was significantly different at $p<0.05$, where post-hoc Tukey’s HSD test result showed a significant difference between Treatment 1, Treatment 2, Treatment 3, and Control treatment. Table 4.2.1 stated that Treatment 2 shows the highest mean for plant height even the light intensity for this treatment is not the highest between other treatments.

Based on table 4.2.1, the mean for leaf width showed a significant difference between Treatment 1, Treatment 2, Treatment 3, and Control treatment which is significant value was 0. 00 meaning that significantly different at $p<0.05$. By using post-hoc Tukey’s HSD test, Treatment 3 showed the higher leaf width compared with others. But when compared with light intensity, Control treatment has a higher PPFD value. While Treatment 1 has the lowest mean for leaf width.

After harvesting all the samples in each treatment, the butterhead were weighed. Again, table 4.2.1 states that Treatment 3 has the highest plant fresh weight between other treatments. The significant value was 0.03 meaning that significantly different at $p<0.05$. In contrast, Treatment 1 shows the lowest plant weight.

After all, a previous study discovered that lettuce cultivars grown in white treatments had a high green light transmittance through the leaf. Thus, red, and blue light can drive photosynthesis in the upper leaf layers of white treatments, whereas green light can drive photosynthesis in the lower leaf layers and canopy, resulting in increased whole-plant photosynthesis and subsequent plant growth (Lin, Huang & Yang, 2013). In other words, the result for this study shows that is it true that increasing light intensity can increase the yield for butterheads. But at the same time, the different light treatments also played an important role to support plant growth in producing the best quality for butterheads.

Table 4.2.1: Mean of plant height, leaf width, and fresh weight for Butterhead.

Group	Plant Height	Leaf width	Plant Fresh Weight
Control	21.14[a]	3.39[a]	4.46[a]
Treatment 1	19.67[a]	2.40b[b]	1.48[b]
Treatment 2	21.16[a]	2.60[b]	2.74[ab]
Treatment 3	16.87[b]	3.41[a]	4.63[a]

*Means separation in each column followed by the same letter are not significantly different at p=0.05

4.2.2 Chlorophyll Value (SPAD) analysis

In plants, chlorophyll is responsible for absorbing light and transferring it throughout the plant during photosynthesis (Writer., 2020). The importance of light treatment can help to enhance light absorption in plants. Table 4.2.2 shows the mean chlorophyll value (SPAD) for butterheads. The chlorophyll value (SPAD) was analyzed using the post-hoc Tukey's HSD test. The data mean for chlorophyll value (SPAD) for week 3, week 4, and week 6 shows a significant difference between each treatment which is $p<0.05$. Despite that, the data mean for week 5 was not significantly different between each treatment when the $p>0.05$.

From the table, the increase of chlorophyll value can be seen for each treatment. But Treatment 3 shows the highest chlorophyll value for every week. According to Coelho et al. (2021), the blue light wavelength produced by White LED light is critical for chlorophyll synthesis, chloroplast development, and photomorphogenesis. Blue light regulates enzyme activation and increases gene expression in the chlorophyll biosynthesis pathway (Fan et al. 2013). The difference can be seen when on week 3, and week 4, the chlorophyll value for the Control treatment was the lowest below Treatment 1 and Treatment 2 (Table 4.2.2). On week 5, and week 6 the chlorophyll value for Control treatment increased to the third-highest and make Treatment 1 became the lowest of all treatments.

Table 4.2.2: Mean of Chlorophyll Value (SPAD) for Butterhead

Group	Week 3	Week 4	Week 5	Week 6
Control	12.61^{b}	18.52^{c}	25.51^{a}	32.14^{ab}
Treatment 1	14.54^{b}	19.18^{bc}	22.42^{a}	26.46^{b}
Treatment 2	15.24^{b}	21.92^{ab}	26.16^{a}	33.29^{a}
Treatment 3	19.69^{a}	24.70^{a}	28.19^{a}	34.11^{a}

*Means separation in each column followed by the same letter are not significantly different at p=0.05

4.2.3 Nitrogen content

According to table 4.2.3, Treatment 3 had the highest nitrogen content, followed by Treatment 1, Control treatment, and Treatment 2. Nitrogen (N) is critical for plant growth and development (Wang et al., 2002). Nitrate is a very abundant nitrogen source in both natural and agricultural systems. By supplementing red and blue light with green light, it is possible to improve nitrate assimilation by increasing the activity and expression of nitrate assimilation. Terashima et al. (2009) reported that green light, typically found in white light, was more efficient at driving photosynthesis than red light.

Table 4.2.3: Nitrogen Content for butterhead.

Type Of Treatment	Nitrogen Content (%)
Treatment 1	0.462231
Treatment 2	0.266133
Treatment 3	0.504252
Control	0.42021

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study demonstrated the positive effects of using LED light on improving the growth and quality of butterhead lettuce crops grown in indoor farming. At the same electrical power, white LEDs light with a combination of other light wavelengths provided a higher PPFD compared to treatment than only use red and blue light combination. It also increased the growth and yield rate for butterheads such as plant height, leaf width and plant fresh weight.

The application of LED light with high light intensity can enhance the growth of butterheads that grew in indoor farming. From the studies, the result showed Treatment 3 and control treatment with high PPFD which is 120.50 μ mol m^{-2} s^{-1} and 123.41 μ mol m^{-2} s^{-1} showed the best and efficient growth for butterhead plant. In addition, a suitable light ratio must be applied correctly to make sure plants grow well. Other than that, the effect of using different light intensities with the aid of suitable light treatment can also increase the chlorophyll content in the butterhead leaf.

The results of this study suggest that the use of white LED with combination red and blue LED light can be favorably used to grow butterhead as well as other leafy vegetables in indoor farming to enhance the quality production of leafy vegetables. Therefore, the best light used in treatment 3 for the application of indoor farming using the artificial light since the efficient result of butterhead yield in treatment 3 for the leaf width and plant fresh weight is essential for butterhead that will be sold to the consumer.

5.2 Recommendation

Future studies should be done to identify the maximum light intensity to enable farmers to maximize the quality of butterheads and increase the production of butterheads for their farms. The light intensity used in this study is not the perfect one due to the lack of source and cost to get the optimum light intensity light for indoor farming. Usually, the indoor farming industry is more advance in the preparation of their LED growth light. They adjust their LED light wavelength precisely based on their plant stage growth. Other than that, using a suitable rack can also improve the plant. By using a rack that can adjust the distance from the plant to the light source, the problem such as excessive light receive for the plant can be prevented efficiently.

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APPENDICES

Appendix A

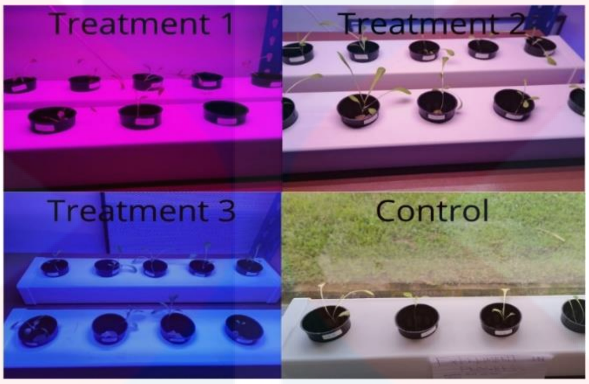

Figure A1: Treatment 1 until three with one control treatment under different light intensity and light sources.

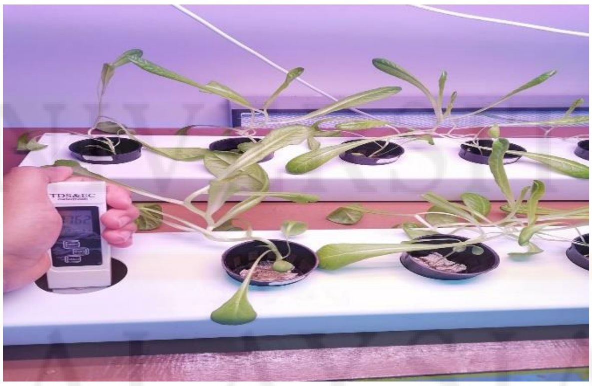

Figure A2: Process of taking EC value for nutrient water using EC Meter

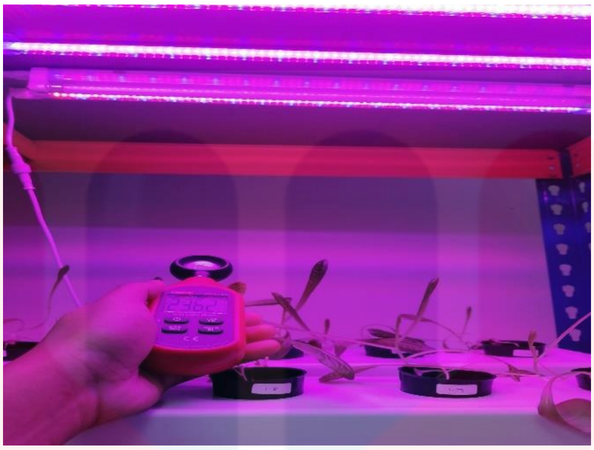

Figure A3: Process of measuring light intensity using Lux Meter

Figure A4: Process to measure pH value for each treatment using pH Meter.

Figure A5: Measuring plant height after harvest using ruler

Appendix B

Table B1: ANOVA table for plant height, leaf width and plant fresh weight

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PLANT_HEIGHT	Between Groups	122.146	3	40.715	12.244	.000
	Within Groups	119.710	36	3.325		
	Total	241.856	39			
LEAF_WIDTH	Between Groups	8.302	3	2.767	12.808	.000
	Within Groups	7.778	36	.216		
	Total	16.080	39			
PLANT_WEIGHT	Between Groups	67.537	3	22.512	5.480	.003
	Within Groups	147.889	36	4.108		
	Total	215.426	39			

Table B2: ANOVA table for SPAD Meter (week 3)

ANOVA

SPAD METER WEEK 3

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	80.604	3	26.868	12.502	.002
Within Groups	17.192	8	2.149		
Total	97.796	11			

Table B3: ANOVA table for SPAD Meter (week 4)

ANOVA

SPAD METER WEEK 4

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	71.886	3	23.962	20.461	.000
Within Groups	9.369	8	1.171		
Total	81.255	11			

Table B4: ANOVA table for SPAD Meter (week 5)

ANOVA

SPAD METER WEEK 5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	43.799	3	14.600	2.646	.130
Within Groups	38.624	7	5.518		
Total	82.423	10			

Table B5: ANOVA table for SPAD Meter (week 6)

ANOVA

SPAD METER 6

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	107.564	3	35.855	6.918	.013
Within Groups	41.464	8	5.183		
Total	149.027	11			

Table B6: Tukey HSD test for plant Height

PLANT HEIGHT

Tukey HSD[a]

TREATMENT	N	Subset for alpha = 0.05	
		1	2
TREATMENT 3	10	16.8700	
TREATMENT 1	10		19.6700
CONTROL	10		21.1400
TREATMENT 2	10		21.1600
Sig.		1.000	.278

Means for groups in homogeneous subsets are

Table B7: Tukey HSD test for leaf width

LEAF WIDTH

Tukey HSD[a]

TREATMENT	N	Subset for alpha = 0.05	
		1	2
TREATMENT 1	10	2.4000	
TREATMENT 2	10	2.6000	
CONTROL	10		3.3900
TREATMENT 3	10		3.4100
Sig.		.772	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table B8: Tukey HSD test for plant weight

PLANT WEIGHT

TREATMENT	N	Subset for alpha = 0.05	
		1	2
TREATMENT 1	10	1.4800	
TREATMENT 2	10	2.7370	2.7370
CONTROL	10		4.4610
TREATMENT 3	10		4.6340
Sig.		.516	.175

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table B9: Tukey HSD test for SPAD meter (week 3)

SPAD METER WEEK 3

	TREATMENT	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	CONTROL	3	12.6133	
	TREATMENT 1	3	14.5433	
	TREATMENT 2	3	15.2433	
	TREATMENT 3	3		19.6900
	Sig.		.204	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table B10: Tukey HSD test for SPAD meter (week 4)

SPAD METER WEEK 4

Tukey HSD[a]

TREATMENT	N	Subset for alpha = 0.05 1	2	3
CONTROL	3	18.5233		
TREATMENT 1	3	19.1800	19.1800	
TREATMENT 2	3		21.9233	21.9233
TREATMENT 3	3			24.7000
Sig.		.877	.057	.054

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 3.000.

Table B11: Tukey HSD test for SPAD meter (week 5)

SPAD METER WEEK 5

Tukey HSD[a,b]

TREATMENT	N	Subset for alpha = 0.05 1
TREATMENT 1	3	22.4233
CONTROL	3	25.5133
TREATMENT 2	3	26.1567
TREATMENT 3	2	28.1850
Sig.		.093

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 2.667.

Table B12: Tukey HSD test for SPAD meter (week 6)

SPAD METER WEEK 6

Tukey HSD[a]

TREATMENT	N	Subset for alpha = 0.05	
		1	2
TREATMENT 1	3	26.4600	
CONTROL	3	32.1433	32.1433
TREATMENT 2	3		33.2867
TREATMENT 3	3		34.1167
Sig.		.061	.721

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.