A STUDY ON THE EFFECT OF DIFFERENT LED LIGHTING ON THE GROWTH OF GREEN ONION (*ALLIUM FISTULOSUM*)

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"A STUDY ON THE EFFECT OF DIFFERENT LED LIGHTING ON THE GROWTH OF GREEN ONION (*ALLIUM FISTULOSUM*)"** was prepared by **LEAN CHYNG YEE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Urbanisation has reduced land for agricultural purposes. Greenhouse or vertical farming system is a more space-, cost- and time-saving method to grow greens. Plants were grown under natural lighting conventionally. The present study focuses on growth of plants under Light Emitting Diodes (LED) lighting which may potentially overcome the problems encountered by the traditional method. The aim of this research is to provide a conducive yet more efficient environment for the development of plants. By conducting this research, the best and most efficient LED colour for planting greens and optimal duration of light exposure to the plants in a greenhouse can be known. Green onions (*Allium fistulosum*) were grown under mixture of red and blue LEDs, solely red LEDs and only blue LEDs. An additional control set where green onions were exposed to sunlight was performed to allow comparison of result. Responding variables were the number of leaves, height and weight of plant. Green onions under the light influence of blue LEDs lead in all the parameters concerned. Furthermore, green onions exposed to lights for 12 h have a more positive result than those exposed for 6 h. Thus, green onions are best to be cultivated in blue LEDs for 12 h.

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DSM	Direct Sowing Method
FAO	Food Agricultural Organization
GDP	Gross Domestic Products
HPS	High Pressure Sodium
LED	Light Emitting Diode

CHAPTER 1

INTRODUCTION

1.1 General Introduction

A favourable environment would be necessary for growth of any living organisms on Earth. By using the concept of greenhouse, a microclimate of optimal conditions can be created to maximize crops production. Microclimates such as temperature, humidity, concentration of carbon dioxide and light intensity can be controlled and monitored closely in a greenhouse horticulture (Kumar, et al., 2006). An enclosed surrounding for plantation can prevent crops from being affected by exterior environments that might be harmful or delay its growth progress. Crops would be protected from harsh weather conditions such as strong winds or heavy rains and pests that will reduce the quality of the plantation (Brandon, et al., 2016).

Among all the factors that contribute to growth of plants, light plays one of the most important roles. In a space-constrained area, plants will not get enough sunlight because there is limited window space that enables natural light sources to reach plants (Sagers, 1994). Furthermore, in countries with four seasons, it is hard to predict the changes in natural lighting. Most countries with winter seasons will experience the scenario of insufficient daylight to supply energy for growth of plants. To overcome the low crop productivity during unpredictable climate change, greenhouses with artificial lighting can mitigate the situation (Gupta and Agarwal, 2017).

There are three types of facilities to grow indoor plants and are categorized based on the type of light source supplied; (a) sunlight, (b) combination of both sunlight and artificial lighting, (c) enclosed surrounding equipped with artificial lighting only. In a situation whereby the surrounding conditions change inconsistently and rapidly, it would be preferable to adapt the third category of light source in the greenhouse, which is installation of artificial lighting in it.

1.2 Importance of the Study

Agriculture plays a big part in sustaining the well-being of humankind. It shares a major role in the Gross Domestic Products (GDP) in the 1950s. However, globalization has caused depreciation in the GDP contributed by the agricultural sector over the past decades as other sectors, such as the industry and services sectors, started to take over. Contribution of the agricultural sector to GDP experiences a drop from 50% to 14% from 1950 to 2010 as illustrated in Figure 1.1 (Rajneesh, n.d.).

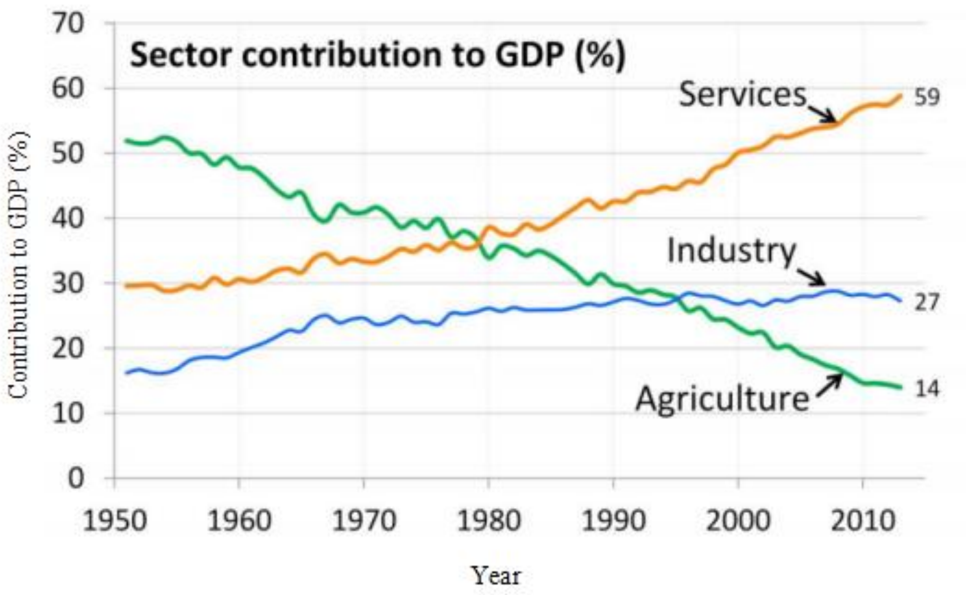

Figure 1.1: Contribution of Service, Industry and Agricultural Sector to GDP From 1950 to 2010 (Rajneesh,n.d.).

Other than that, the demand for food and crops has increased tremendously with the fast-paced level of globalisation and growth of the world population. Earth was predicted to have a 9.1 billion population by year 2050. Hence, the Food Agricultural Organization (FAO) states that the production of food must be increased by 70% to fulfil the demand (Pinho and Halonen, 2014). Traditional farming was widely practiced in open areas and is always affected by external factors. In recent times, there had been an attack of locusts in India and Pakistan amid the Covid-19 outbreak. Biswas (2020) mentioned that the swarm has invaded over two dozen districts which covers up to 50,000 hectares of western India. These swarms of locusts decreased the production of crops dramatically and increased the selling price of goods uphill. The crops eaten by the locusts are equivalent to food consumed by 35,000 people per day. With the aid of indoor greenhouse horticulture, the crops will not be affected by climate changes and natural disasters as mentioned above because they would be in a closed and controlled environment.

1.3 Problem Statement

The requirements such as exposure to light source and soil moisture varies from plant to plant. Since this is an indoor greenhouse study, control of such requirements is of essence and has room for development. To date, growing plants using LED is not widely practiced yet as compared to application of lighting on human vision (Pinho and Halonen, 2014). Other factors that might affect the performance of indoor greenhouse horticulture using LED are the unpredictable external factors such as pest infestation and lifespan of the plant.

1.4 Aim and Objectives

The aim of this project is to create a conducive enclosed environment for indoor growing of plants. The objectives include:

1. To investigate the effect of LED lighting on plant growth based on various LED wavelength.
2. To evaluate if LED light source can replace sunlight to grow green onions (*Allium fistulosum*) in a mini greenhouse.

1.5 Scope and Limitation of the Study

The development and growth rate of a plant is affected by the type of LED lighting used in a greenhouse. Hence, the study on the effect of different types of LED lighting on plant growth in an enclosed environment is vital. The size of a greenhouse is greatly affected by the type of plant chosen to be planted in it. Chemicals such as pesticides and fertilizers are not used in this project as organic greens are healthier. Experiments involving biological samples such as growth of plants might be hard to control and there will be instances where outliers are common and it may need more than two repetition to get a result which can properly represent the average value. However, due to time limitation, the experiment for each set was only carried out once but with three onions under each light condition to obtain the mean value.

CHAPTER 2

LITERATURE REVIEW

2.1 Photosynthesis

Photosynthesis is the process whereby plants utilize the light energy from sunlight and convert it into chemical energy. Sunlight transfers the electrons from water molecules to carbon dioxide, producing carbohydrate for the plant. In the meantime, oxygen is produced with the carbohydrate (Vidyasagar, 2018).

$$6CO_2 + 12H_2O + Light\ Energy \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O \qquad (2.1)$$

Based on Equation 2.1, six molecules of carbon dioxide react with twelve molecules of water and with the aid of light energy, one molecule of carbohydrate, six molecules of oxygen and six molecules of water are formed (Vidyasagar, 2018). Plants have organelles called chloroplasts which are made up of chlorophyll, a light-absorbing pigment. During the process of photosynthesis, chlorophyll absorbs the light energy from the light source and reflects green-light waves. Hence, resulting in the green appearance of the plants (National Geographic Society, 2019).

Chlorophylls are green-colored pigments as discussed above. On the other hand, carotenoids are red, yellow or orange-colored pigments which have the ability to capture bluish-green lights and can be found in carrots, pumpkins, sweet potatoes, spinach and kale (BD Editors, 2018). Phycobilins absorbs other wavelengths of light which are not well absorbed by chlorophylls and carotenoids. They appear as red or blue-colored and can often be found in red algae and cyanobacteria (Vidyasagar, 2018).

2.2 Light Emitting Diode (LED)

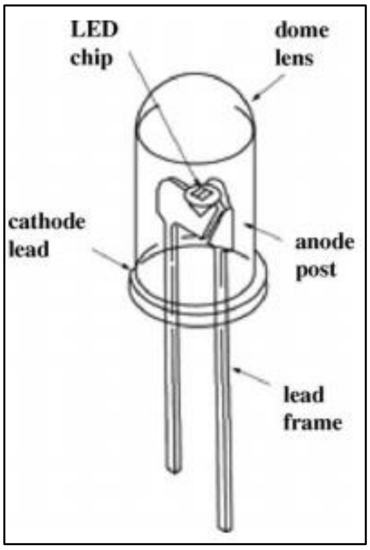

Figure 2.1: Structure of a LED (Yeh and Chung, 2009).

LED is a special semiconductor diode whereby it consists of a chip doped with impurities. It has a p-side (anode) and n-side (cathode), known as the p-n junction. Current flows in a single direction, from anode to cathode in a LED. The development of LED started with infrared and red devices obtained from gallium arsenide. Advancement in technology has created devices that are able to produce lights of shorter wavelengths, hence, various colours (Yeh and Chung, 2009).

2.2.1 LED Lighting for Greenhouse Horticulture

In the late 1960s, Nick Holonyak Jr invented the first GaAsP LED with the combination of three primary elements, which are gallium, arsenic and phosphorus. It provides a 655 nm red light with a brightness level of 1-10 mcd with a supply of 20 mA current. In the next decade, more colours were invented by manipulating the wavelengths of the light source. GaAlA (gallium aluminium arsenide) material was found in the 1980s and it has a much better performance than the previous inventions as it required lower voltage to power up the invention. Further down the timeline, InGaAlP (indium gallium aluminium phosphide) was developed and more colours were discovered (Yeh and Chung, 2009).

As shown in Figure 2.2, in the late 1980s, study on usage of LED lighting for growth of plants began but it is only limited to 660 nm discrete LEDs. Further down the years when it reached the mid-1990s, LEDs were used for plant research and blue LEDs were available in the market. By the end of 1990s, LEDs with the power rating of 1 W were invented and Japan had its first commercialized LED plant production. Advancement of technologies in the 2000s had fastened the pace of LED inventions. Lights with multispectral output, higher power, more adaptive ability and provides a large efficiency and high-performance LEDs were invented. In 2003, LED house plants were commercialized and a few years later, LEDs were widely used for in-canopy lighting and greenhouses (Morrow, 2008).

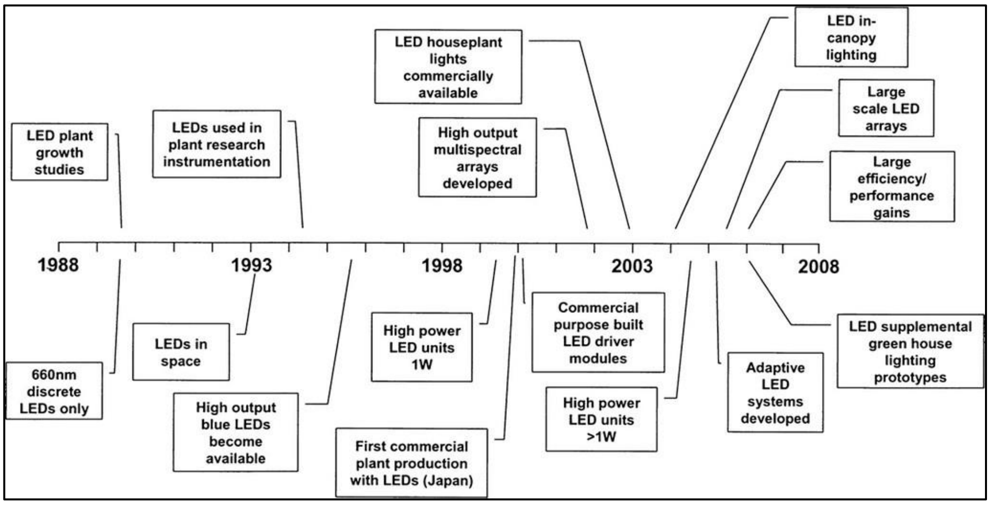

Figure 2.2: Timeline of Development of LED Lighting in Horticulture (Morrow, 2008).

2.2.2 Types of LED

Photosynthesis is mostly stimulated by lights with wavelengths ranging between 400 nm and 700 nm (Nederhoff, 2010). There are three colours of LED that are widely used for horticulture purpose, which are the blue, green and red lights. Blue lights are in the region of 400 to 500 nm, green lights are in the 500 to 600 nm region while red lights have the longest visible light wavelength of 600 to 700 nm (Intelligent LED Solutions, 2020).

Runkle (2016) mentioned that red LEDs have the best efficiency recorded in converting electrical energy into photosynthetic photons to be used in photosynthesis. However, the plants appear to be elongated with thin and large leaves. Plants with these characteristics are not desired and hence blue lights are combined with red LEDs to promote the stem growth and it resulted in smaller and more compact leaves. Table 2.1 shows the effect of different wavelength regions on plant growth.

Table 2.1: Effects of Different Regions of Wavelength on Plant.

Wavelength range (nm)	Photosynthesis	Effects	Source
200 - 315		Harmful	
315 - 380			
380 - 400	Yes		
400 - 500 (Blue)	Yes	Strong and healthy leaves and stems	(Baessler, n.d.)
		Promotes photomorphogenic functions such as control of the stomata, growth of stem and phototropism	(Intelligent LED Solutions, 2020)
500 - 600 (Green)	Some	Vegetative growth	(Intelligent LED Solutions, 2020)
600 - 700 (Red)	Yes	Aids seed germination and root growth for plants in their early stage	(Baessler, n.d.)
		Boosts growth of fruits and flowers	(Intelligent LED Solutions, 2020)
700 - 1,000 (Far red)		Germination, leaf budding and growth, flowering, controls height of plant and flower blooming time	(Intelligent LED Solutions, 2020)
> **1,000**		Converted to heat	

Based on Figure 2.3, green light has the least efficiency as compared to blue and red lights. This condition is due to inefficiency of absorption of green light by chlorophylls in the plant. Leaves appear as green because most of the green light was reflected into human eyes. Although green light does not play a big role in photosynthesis, it has its unique characteristics in aiding plant growth as well as in humans. Wollaegar (2014) mentioned that green lights are less harmful to human eyes as compared to other lights used in horticulture. Other than that, green light has a better ability to penetrate the canopy, allowing lower leaves to perform photosynthesis.

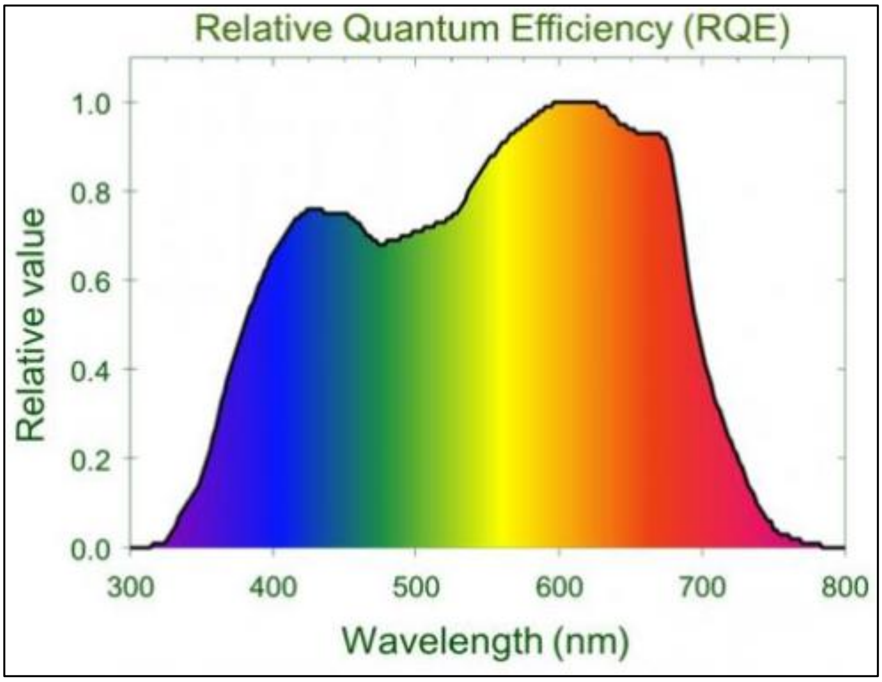

Figure 2.3: Relative Quantum Efficiency Curve (Mashkkov, et al., 2017).

2.2.3 Pros and Cons of LED Lighting in Greenhouse Horticulture

LED and High Pressure Sodium (HPS) lamps are the most common artificial lighting provided in the industry to aid in plant growth. Assessment of the pros and cons of LED lighting will be compared to HPS lamps in a greenhouse horticulture.

Table 2.2: Merits and Limitations of LED Lighting in Greenhouse Horticulture.

Merits	Limitations
- Higher efficiency than HPS lamps - Improved quality of plants - More uniform light distribution - Reduced heat and radiation as energy obtained is focused on conversion to light energy - Low operational cost - Long lasting	- Limited coverage area because of the small size - Purchase cost is high - Light intensity reduces as it ages - Blue LEDs are harmful to human eyes

LED technology in horticulture is more efficient as compared to the other conventional light sources due to the amount of photons being released per kWh. As shown in Figure 2.4, the efficiency of LED is higher than High Pressure Sodium (HPS) lights as the electrical energy obtained from the source is mostly converted into light energy. In the HPS light, the majority of the electrical energy is turned into radiation heat instead. Quality of plants can be improved through selection of the light spectrum. There are a variety of colours in LEDs and each of them has their own strengths. Type of LED can be chosen based on the requirement of the seedling and the light can be changed as it grows depending on its necessity (Rajneesh, n.d.).

Other than that, LEDs provide a more uniform light distribution than other light sources. Due to its small size, plants below the canopy area would be able to obtain light sources as well. Infrared or radiation heat will not be an issue as the output of the energy is biased towards light energy instead of radiation heat as shown in Figure 2.4. Excessive radiation heat may be harmful to heat-sensitive plants and extra air-conditioning will be required to cool down the greenhouse if HPS lamps were used (Rajneesh, n.d.).

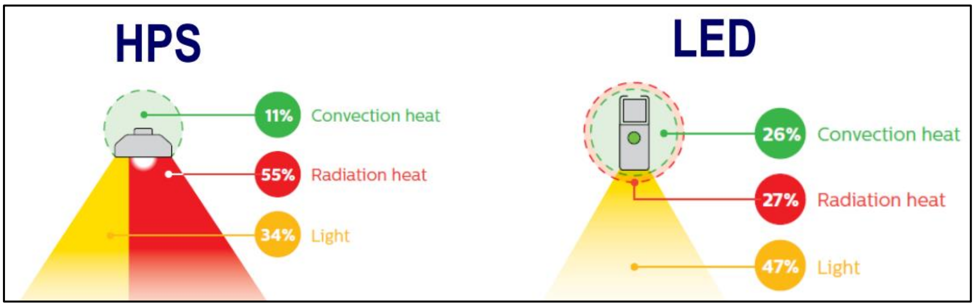

Figure 2.4: Comparison of Efficiency Between LED and HPS Lights (Rajneesh, n.d.)

Furthermore, operational cost is significantly reduced as the wattage and energy use of LED is lower than HPS. The lifespan of LEDs is longer than HPS as shown in Table 2.3. Hence, the maintenance cost can be saved, and it will not be necessary to change LEDs frequently (CSea, 2012).

Table 2.3: LEDs Versus HPS Lamps (CSea, 2012)

Fixture Type	Wattage (W)	Lifespan		Energy Use (24 h/day)	Annual Cost (maintenance + electricity)
		h	Yrs	Annual	At $ 0.11/kWh
HPS	191	24 000	2.7	1 674 kWh	$ 195
LED	78	50 000	5.7	683 kWh	$ 75

As for the downside of LED lighting application in a greenhouse, LEDs produces directional light as the beam produced has a limited area of coverage as compared to conventional lighting systems. Cost of LEDs are more expensive in short term investments as the purchasing cost is high. However, in the long run, the maintenance cost and electricity bills can cover up the purchase cost. Aging effect on LEDs cannot be prevented. Although LEDs are long lasting, but the power might decline as they age and fail to produce the expected light quality consistently to the plants (Steven, 2020). Furthermore, blue LEDs are good for the plants but it is harmful to human eyes. Long exposure to bright blue lights might cause blindness as it damages the retinal cells (Advanced Nutrients, 2019).

Samuoliene, et al. (2009) investigated the effect of treating leafy vegetables grown under HPS lamps and further treated with red LEDs three days before harvesting. Nitrate content in the plants treated with red LEDs were greatly reduced by two to three times (44% to 65%) when compared to those who were solely grown under HPS lamps as shown in Figure 2.5. Other than that, Figure 2.6 shows a significant increase in the concentration of carbohydrate in all the plants studied because the supply of red light can increased the rate of photosynthesis in plants. It was observed that the significant increase in carbohydrate content is leaned towards monosaccharides (fructose and glucose), which have a higher nutritional value than disaccharides (maltose).

Figure 2.7 shows the comparison of Vitamin C content in plants with and without the treatment of red LEDs prior to harvesting. In the leaves of green onion plants, the Vitamin C content had increased by 25% while marjoram and hydroponic lettuce remains almost unchanged while peat-grown lettuce showed a drop of 46%. The sudden decrease in Vitamin C content of peat-grown lettuce may be caused by the spike in concentration of carbohydrate, which triggered aging of the leaves and hence, overmaturing the plant. Thus, this shows that LEDs are better than HPS lamps at providing light energy to plants for growth and development.

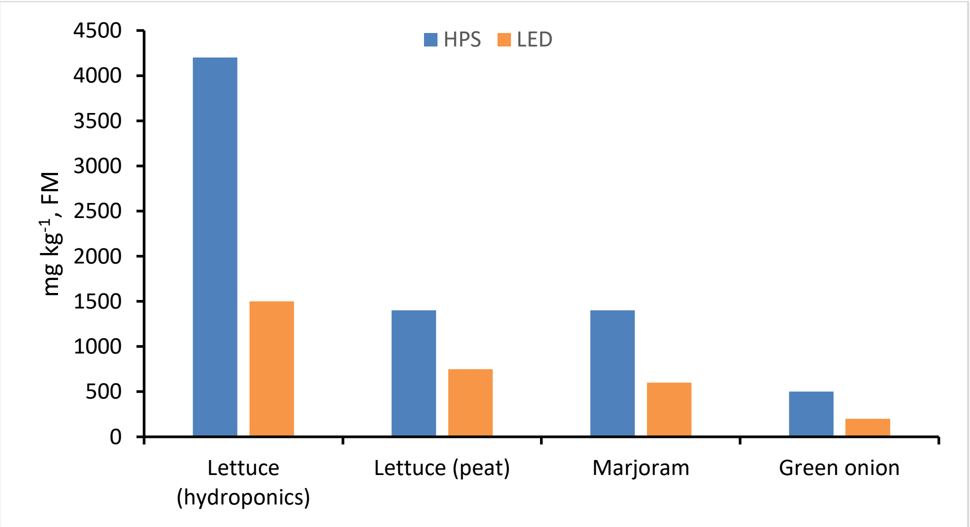

Figure 2.5: Concentration of Nitrate in Plant Grown Only Under HPS (Left Columns) Compared With Plants Treated Under Red LEDs (Right Columns) Three Days Prior Harvesting (Samuoliene, et al., 2009).

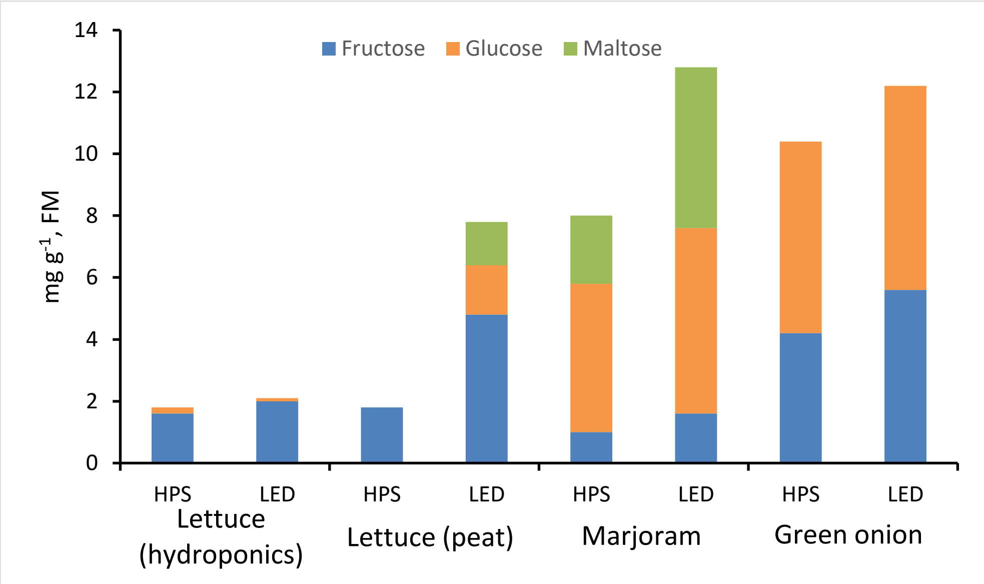

Figure 2.6: Concentration of Carbohydrate in Plant Grown Only Under HPS (Left Columns) Compared With Plants Treated Under Red LEDs (Right Columns) Three Days Prior Harvesting (Samuoliene, et al., 2009).

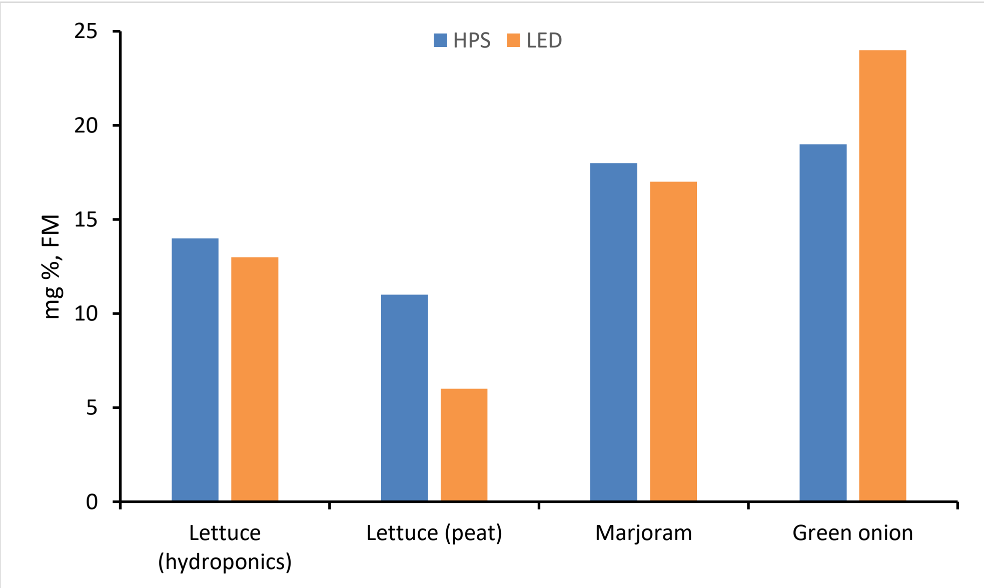

Figure 2.7: Concentration of Vitamin C in Plant Grown Only Under HPS (Left Columns) Compared With Plants Treated Under Red LEDs (Right Columns) Three Days Prior Harvesting (Samuoliene, et al., 2009).

2.3 Types of Greens Suitable for Plantation in Mini Greenhouse

Plants have their respective desired LED lighting colour. By choosing the right colour for the plant, it will have a positive effect on the plant growth. Various experiments had been carried out on assorted species of plants to study the effect of different LED wavelengths on the plant physiology. Table 2.4 shows the impact of different LED lighting colour on selective plant species (Singh, et al., 2015).

Table 2.4: Response of Plants to Different Light Sources (Singh, et al., 2015).

LED Source			**Plant Name**	**Response of plants**
Blue	**Green**	**Red**		
+			Cabbage	High chlorophyll content and petiole elongation is promoted
	+		Red leaf lettuce	Enhanced growth
		+	Tomato	Increased tomato yield
		+	Kale	Increase in accumulation of lutein and chlorophyll
		+	Lettuce	Reduced nitrate content
		+	Green onion	
+	+	+	Cherry tomato	Increased net rate of photosynthesis and number of stomata

There are two main factors to be considered when choosing a plant for a mini greenhouse. The duration needed for the plant to mature and size of the plant will affect the decision as there is time and space constraint for this project. Table 2.5 and Table 2.6 shows the duration needed for selective plants to mature via Direct Sowing Method (DSM) and under LED lighting, respectively.

Table 2.5: Time Needed for Plants to Mature Via DSM.

Plant	**Duration needed for plant to mature via DSM**	**Source**
Cabbage	80-180 days	(Albert, n.d.b)
Red leaf lettuce	45-55 days	(Carter, 2020a)
Tomato	50-60 days	(Jabbour, n.d.)
Kale	45-70 days	(Albert, n.d.c)
Lettuce	45-55 days	(Carter, 2020a)
Green onion	20-30 days	(Allman, n.d.)
Cherry tomato	60-80 days	(Allen, 2011)

Table 2.6: Time Needed for Plants to Mature Under LED Lighting.

Plant	**Duration needed for plant to mature under LED Lighting**	**Source**
Cabbage	70-100 days	(Averin, n.d.a)
Red leaf lettuce	70-100 days	(Averin, n.d.a)
Tomato	45-85 days	(Averin, n.d.b)
Kale	70-100 days	(Averin, n.d.a)
Lettuce	70-100 days	(Averin, n.d.a)
Green onion	40-50 days	(Dieter, n.d.)
Cherry tomato	45-85 days	(Averin, n.d.b)

On the other hand, Table 2.7 shows the space required for a matured plant and the size of plantation for each species of plant. Some plants that are larger in size require a bigger distance between the seedlings. If the plants are placed too closely to each other, they may compete for resources and result in stunted growth. Hence, a suitable distance between the seedlings is vital.

Table 2.7: Size of Plants.

Plant	**Size of Plant**	**Source**
Cabbage	Average height as the plant is roundish. 24-36 inches between cabbage rows and 18-24 inches apart.	(Albert, n.d.b)
Red leaf lettuce	Short leafy plant. 12-15 inches between lettuce rows and 4-8 inches apart.	(Carter, 2020a)
Tomato	Height of the plant can range from two to eight feet tall and requires support.	(Jabbour, n.d.)

Table 2.7: Size of Plants. (cont.)

Plant	Size of Plant	Source
Kale	Average height. Half inch depth with 18-24 inches apart.	(Albert, n.d.c)
Lettuce	Short leafy plant. 12-15 inches between lettuce rows and 4-8 inches apart.	(Carter, 2020a)
Green onion	Average height as it has shoots above the soil. One inch below the surface of soil. 18 inches between onion rows and 4-5 inches apart.	(Carter, 2020b)
Cherry tomato	Tall plant ranging from 18-36 inches tall. Requires support.	(Albert, n.d.a)

Based on the criteria discussed in Table 2.6 and Table 2.7, the plant chosen to be planted in the mini greenhouse is green onion as it requires the least amount of time to reach maturity and it doesn’t need a huge space for growth. Leafy greens of an onion are called green onion. It is useful in cooking to enhance the flavour of a dish and it can also be used as a garnish for food plating and presentation.

CHAPTER 3

METHODOLOGY

3.1 Design of Greenhouse

Greenhouse was built from scratch to reduce cost and to ensure it will be the desired dimension needed for the project. As all the items are bought separately, from different sellers, the measurements must be precise to make sure everything fits well in the greenhouse. Solidworks software was used to draw the layout of greenhouse and design it to utilize its space efficiently. Firstly, the list of apparatus and materials needed must be determined beforehand. The list below is the compilation of all apparatus and materials used for the project:

1. 4-in-1 organic planting soil
2. Straw board
3. LED grow light
4. Stainless steel storage rack
5. Plastic planter box
6. Mini pocket scale
7. 4-in-1 soil analyser
8. USB port hub
9. Ruler
10. Oven

A total of 5 kg of organic soil was purchased as the growth medium. The soil medium was changed after every set to maintain the consistency in quality of the soil. Greenhouse is an enclosed environment for the growth of plants. Hence, unnecessary light influence from the surrounding should be avoided. Six large black straw boards with dimensions of 68 cm by 76 cm were purchased. Straw boards were chosen to be the cover because they are malleable and can be cut into desired size easily as compared to rigid cardboard. Other than that, straw boards are waterproof. In any case of water spillage or condensation from the photosynthesis process of plants, the water would not cause the cover of the greenhouse to mould.

LED grow light is the main apparatus in this research. Single headed LED grow light was purchased and there are three modes to choose from: red light only, blue light only or both blue and red light. Therefore, three units were bought, and all three modes were utilized and studied in this project. For this model of LED grow light, they are also capable of changing the light intensity based on desirability. The light intensities can be chosen from 20%, 40%, 60%, 80% or 100%. However, for this project, only light intensity of 100% were studied.

Structure of the greenhouse should be solid and strong enough to withstand the weight of all the planter boxes when they were to be placed in it. A shelf with dimensions of 50 cm length, 60.5 cm height and 25 cm width was purchased. The stainless steel storage rack purchased has a unique feature of adjustable length that can range from 50 cm to 85 cm. The length of the shelf was fixed at 60 cm to be able to withhold two planter boxes that will be placed horizontally with a little bit of space allowance between the planter box and the shelf cover.

Planter boxes can have a huge range of shapes and sizes. Four rectangular planter boxes with the dimension of 23 cm in length by 17 cm in width by 8 cm in height were purchased to hold the plant in four different conditions of control set, which is sunlight exposure, red LED, blue LED and mixture of red and blue LED respectively. Base of the planter boxes have holes to allow excess water to drip onto the tray to avoid surplus water content or moisture in the soil. The trays are made from excess straw board that were designed to fit the bottom of the planter box.

Growth of the plant is only determined by the physical characteristics such as the height of plant, number of leaves, fresh and dry weight of the plants. Chemical properties such as the content of chlorophyll in plants couldn’t be observed because the tools are limited. To measure the height of plant, a ruler was used. As for the measurement of fresh and dry weight of the plants, a weighing scale with a small precision is required as the dry weight of the plants might be lesser than 1 g after heated in the oven. Hence, a mini pocket scale with a precision up to 0.1 g was purchased for this project. Dry weight is necessary to be taken in addition to fresh weight because fresh weight is influenced by the water content in the plants. An oven was preheated and set at 100 ℃ for 30 min for all the sets to dry them thoroughly and measured again to obtain the true mass of the plants.

Controlled variables in a greenhouse includes temperature, humidity, light intensity and pH value. To ensure these conditions are always in the desired range of values, 4-in-1 soil analyser was used to measure the temperature, humidity and pH value by inserting a probe gently into the soil. Green onions grow well under temperature of 20 ℃ to 30 ℃, 70% relative humidity (Howell, Cavanagh and Hazzard, 2017) or 25 mL per week per onion (Veggie Gardener, 2017) and a pH value of 6.5 to 7.0 (Oregon State University, 2010).

There are three ways to plant a green onion, which are from seeds, sets or transplants (Hall, 2018). Sets are small onion bulbs that are half mature and partially completed the growth cycle but it has not flowered (Volente, n.d.). They should not have shoots growing out of them when bought from the store and it should be in a well-rounded shape (Kamilla, n.d.).

Table 3.1: Details of Different Plantation Methods.

Plantation Method	**Description**	**Source**
Seeds	Seeds can be sowed directly 0.25 inches to 0.50 inches deep into the soil with a gap of 4 inches apart. It requires a warm climate with an approximate 12 h of light.	(Butterfield, 2014)

Table 3.1: Details of Different Plantation Methods (cont.)

Plantation Method	**Description**	**Source**
Sets	Sets are sowed directly into the soil with a depth of 1 inch and with a gap of 4 inches between sets.	(Kamilla, n.d.)
Transplants	Cut approximately 1 inch of the white area from the bulb or roots of an onion. There are two ways of transplanting, which are with soil or with water. If soil is used, place them evenly across the soil bed and water them. On the other hand, if only water is used, place them in the water and watch them grow.	(Samira, 2020)

Transplanting will be the best method to be carried out as it requires the least amount of time for the plant to reach its maturity and it has the highest success rate than the other two methods. With the dimension of the planter box mentioned above, three onions can be planted simultaneously in one box, under a single LED light exposure. With three onions in a box, the average values of height of plant, number of leaves, fresh and dry weight of plants can be obtained. Other than that, it is necessary to plant more than only one onion under a single condition because in any case of unexpected stunted growth, there will still be backup onions.

Dimension of the greenhouse is 60 cm × 60 cm × 25 cm (length × height × width). The design of the greenhouse is as shown in Figure 3.1. The greenhouse was separated into four compartments of mixture of red and blue LEDs in the top left, controlled set, whereby the onions were exposed to sunlight, in the top right, red LEDs in bottom left and lastly, blue LEDs in the bottom right compartment.

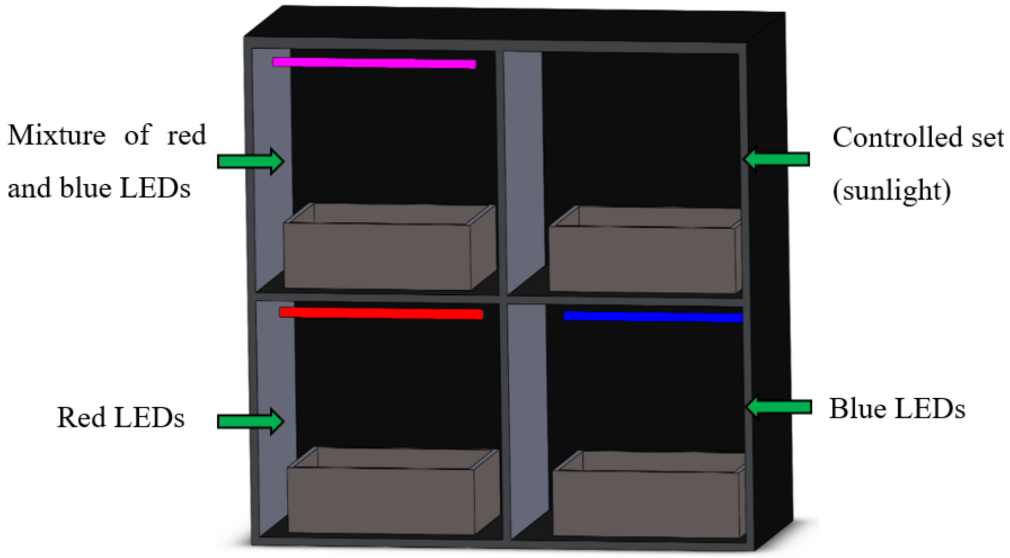

Figure 3.1: Greenhouse Design Drawn Using Solidworks Software.

A greenhouse was built based on the design drawn using Solidworks software. Figure 3.2 shows the actual structure of the greenhouse with the LEDs turned on.

Figure 3.2: Structure of Greenhouse After LEDs Are Turned On.

3.2 Pre-treatment Procedure

Fresh green onions were bought from stores and treated in advance before planting into the soil. Figure 3.3 shows the structure of an onion bulb that can be commonly found in-store. The top part of the onion and tunic were cut off and removed, exposing the immature flower partially. This step is essential to allow light to be able to penetrate through the layers of an onion easily in order for it to perform photosynthesis. The tunics were removed because they will rot under long exposure in soil or in contact with moisture.

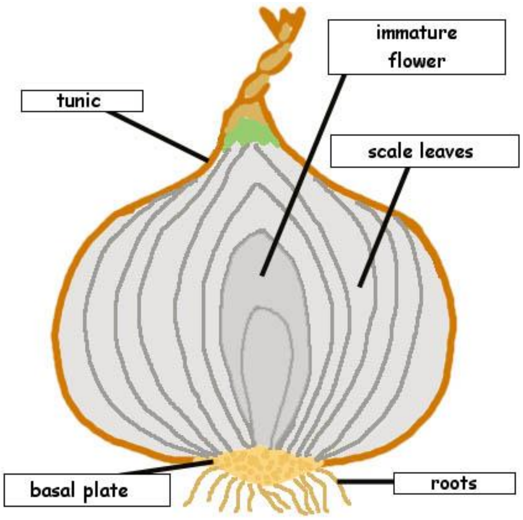

Figure 3.3: Structure of Onion.

After that, onions were pre-treated in water to promote root growth before transferring into planter box containing organic soil. This step is important to speed up the growth of plants and to ensure the plants to grow successfully. Bottom half of the onions were soaked in water for 36 h prior to shifting to a soil bed. Figure 3.4 shows the new white roots growing from the bottom of the onions.

Figure 3.4: Bottom of Onion Bulbs After Soaked in Water for 36 h.

3.3 Monitoring of Plant Growth

In a single set of experiment, there were a total of four conditions tested, which are mixture of blue and red LEDs, solely red LEDS, blue LEDs and controlled set of exposure to sunlight. The entire set was repeated twice with a different duration of light exposure on the plants. The duration tested were 6 h and 12 h. Planter boxes was kept in the greenhouse under dark condition for the remaining hours of the day. For the set of 12 h light exposure, the LED lights are turned on manually daily from 7 a.m. to 7 p.m. for 13 days. On the other hand, for the second set of 6 h light exposure, LED lights were turned on from 12 p.m. to 6 p.m. for the same number of days. As for the control set, the plant was brought out from the greenhouse and was left near a window for photosynthesis process to take place at the same time and for the same duration as those exposed under LED lights. However, the plant is not placed directly under the sunlight because the heat from the sun might accelerate transpiration and water loss in plants as the temperature can exceed 30 °C.

To maintain the humidity of soil and to provide water supply to plants, the plants were watered with 75 mL of water every 5 days. Based on article writeups, it was supposed to be once every 7 days, but with constant humidity monitoring using a 4-in-1 soil analyser, plants tend to lose moisture at 5 days interval. Hence, watering of plants was fixed at every 5 days. Plants will experience an increase in height and diameter of stem, wider leaf size as well as gain in fresh and dry weight in the overall plant as they grow (Pandey, et al., 2017). The duration of plantation was fixed at 13 days with an additional pre-treatment of 36 h. Height and number of leaves grown out of every onion were measured daily at 6 p.m. with a ruler. From there, the average growth of plants per day (cm/day) were calculated and mean number of leaves grown under each type of light exposure can be known.

Fresh weight of a plant was obtained without harming the plant, but it was difficult to get an accurate weight as plants store large amount of water internally. Dry weight of a plant was obtained by drying the plant in an oven at 100 ℃ for 30 min. The plant growth measurement by using dry weight is more accurate and reliable than fresh weight because it is not affected by the amount of water supplied to the plant (Science Buddies, n.d.). By the end of day 13, green onions were chopped off at the same level as the soil bed as shown in Figure 3.5 and weighed for the fresh weight using a mini pocket scale as shown in Figure 3.6. Dry weight of plants was obtained after the oven-drying process. Condition of the plants before and after oven-drying are shown in Figure 3.7.

Figure 3.5: Detachment of Green Onion from the Bulb.

Figure 3.6: Measurement of Fresh Weight of Green Onions on Mini Pocket Scale.

Figure 3.7: Condition of Green Onions Before and After Oven-Dried.

CHAPTER 4

RESULTS AND DISCUSSIONS

The objectives of this experiment were to investigate the effect of LED wavelengths on the growth of green onions and the effect of duration of light exposure on its growth. Hence, the results and discussions would be separated into two parts. To present it in a clearer way, onions grown under 12 h light exposure were labelled as Set 1 and onions grown under 6 h light exposure were labelled as Set 2.

4.1 Effect of LED Wavelengths on Growth of Green Onions

Based on journals and articles found, the recommended duration of light exposure that maximizes the growth of green onions is 12 h. In a single set of greenhouse, 3 different types of LED wavelengths were tested, mixture of red and blue LEDs, red LEDs and blue LEDs. On top of that, there was a set of green onions that were exposed to the sunlight for the same amount of time and it acts as the controlled set. A few responding variables were taken into account in this experiment, such as the number of leaves, height of green onions as well as the fresh weight and dry weight of the plant.

4.1.1 Number of Leaves

The number of leaves grown from a single onion bulb is very subjective as some onions have one bud and some have two buds as shown in Figure 4.1. The bud count may affect the leaf quantity. Hence, the main objective of obtaining the data on the number of leaves was to find out the average height of them in the following section. Table 4.2 shows the average number of leaves grown. The standard deviation of leaf count was very high as they were affected by the quantity of buds in each onion.

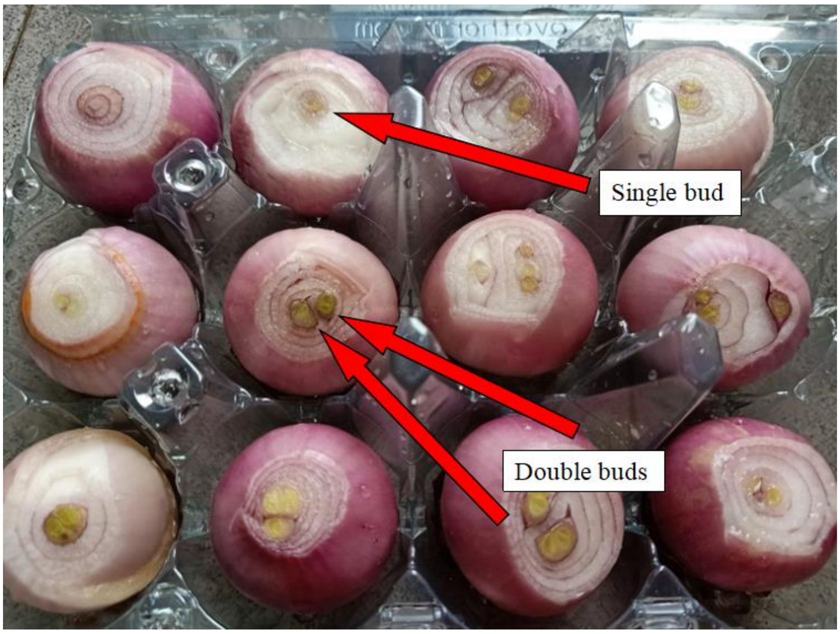

Figure 4.1: Number of Buds in Onion Bulbs.

Table 4.1: Average Number of Leaves Grown for Set 1.

Day	Mix LEDs		Red LEDs		Blue LEDs		Control (Sun)	
	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.	Ave.	S.D.
1	7.0	2.83	7.5	0.71	4.5	4.95	5.0	1.41
2	8.5	3.54	8.0	1.41	7.5	6.36	5.0	1.41
3	9.5	3.54	8.5	2.12	8.5	6.36	7.5	2.12
4	10.5	4.95	10.0	2.83	10.0	8.07	8.0	1.41
5	12.5	3.54	10.5	2.12	10.5	7.78	8.5	0.71
6	13.0	4.24	10.5	2.12	10.5	9.19	9.0	0.00
7	14.0	4.24	11.0	1.41	11.5	7.78	9.0	0.00
8	14.0	4.24	11.0	1.41	12.5	8.49	9.5	0.71
9	15.0	2.83	11.0	1.41	13.0	9.90	9.5	0.71
10	15.0	2.83	11.0	1.41	14.0	9.90	9.5	0.71
11	15.5	3.54	11.5	2.12	14.0	9.19	9.5	0.71
12	15.5	3.54	11.5	2.12	14.5	9.19	9.5	0.71
13	15.5	3.54	11.5	2.12	14.5	9.19	9.5	0.71

*Ave. = Average

S.D. = Standard Deviation

4.1.2 Height of Plant

Plants were exposed to lights for 12 h daily, from 7 a.m. till 7 p.m.. Figure 4.2 and Figure 4.3 shows the growth of green onions on Day 6 and Day 13 respectively. Mix #2 and Red #1 were experiencing stunted growth as compared to the other plants. Hence, they were excluded from calculations. To lower the standard deviation in the research, outliers such as Blue #3 and Control #1 were removed and excluded from calculations.

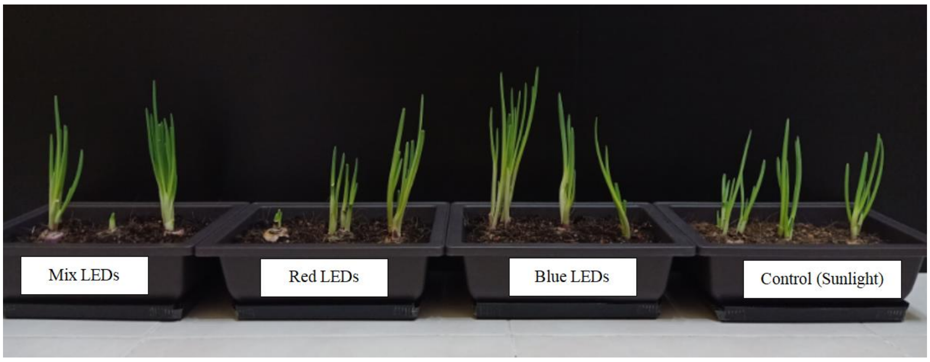

Figure 4.2: Green Onions on Day 6 of Set 1.

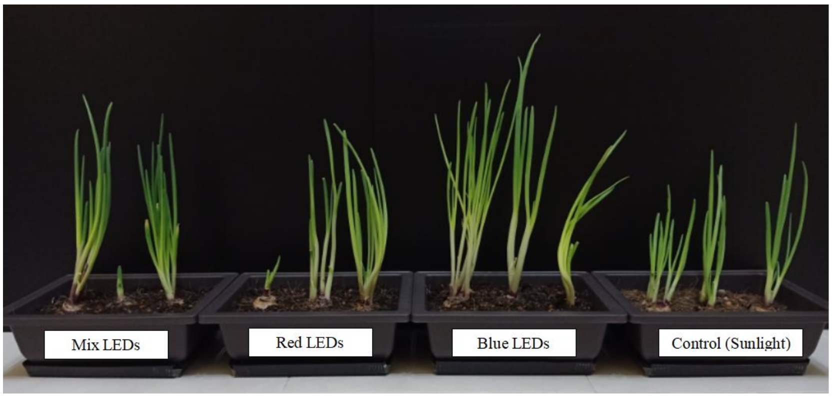

Figure 4.3: Green Onions on Day 13 of Set 1.

Figure 4.4 shows a graph of height of plants versus day that shows the growth progress of green onions throughout the experiment. Green onions exposed to mix LEDs take the lead but as it reaches Day 5, green onions under blue LEDs surpasses. The reason behind this scenario is mix LEDs consist of both blue and red lights that aid in growth during the early stages. As it grows, blue light plays a bigger role in providing nutrients to the plants as they need to grow longitudinally and increase in leaf area. Control set that was exposed to the sunlight remains as the plant that has the least growth. In conclusion, the best light to grow green onions for 13 days with light exposure duration of 12 h is blue light, followed by, mixture of red and blue, red light, and lastly, sunlight.

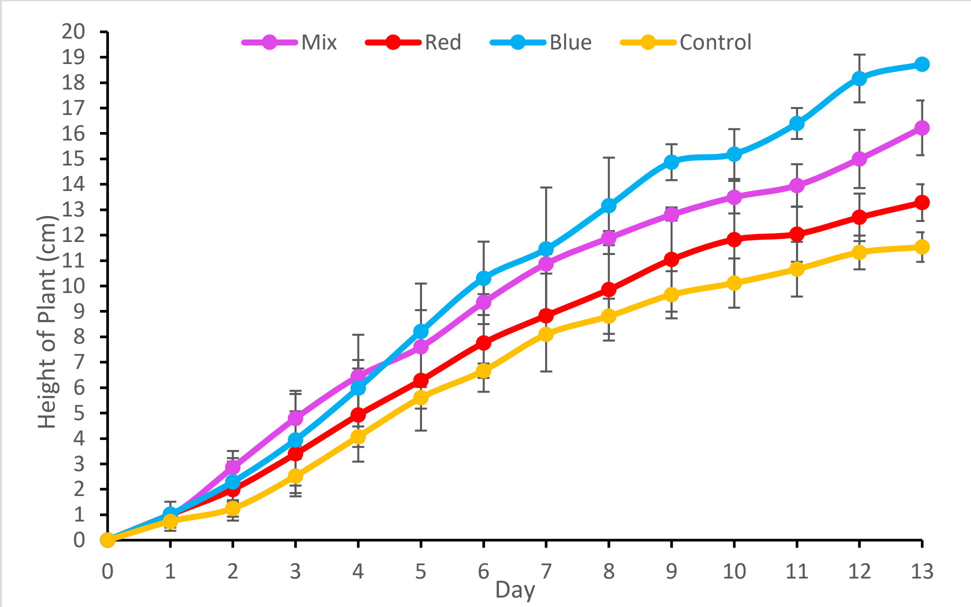

Figure 4.4: Graph of Height of Plants Versus Day for Set 1.

4.1.3 Fresh Weight and Dry Weight of Plant

Other than the number of leaves and height of plants, weight is also a parameter that can be used to determine the health level of plant. However, green onions tend to have a lot of moisture in them. Hence, in this experiment, both fresh weight and dry weight were observed to have a higher accuracy. Weights of the green onions were taken three times and a mean value is calculated to have higher accurateness. Figure 4.5 illustrates the bar graph of average weight of plants under respective light exposure condition.

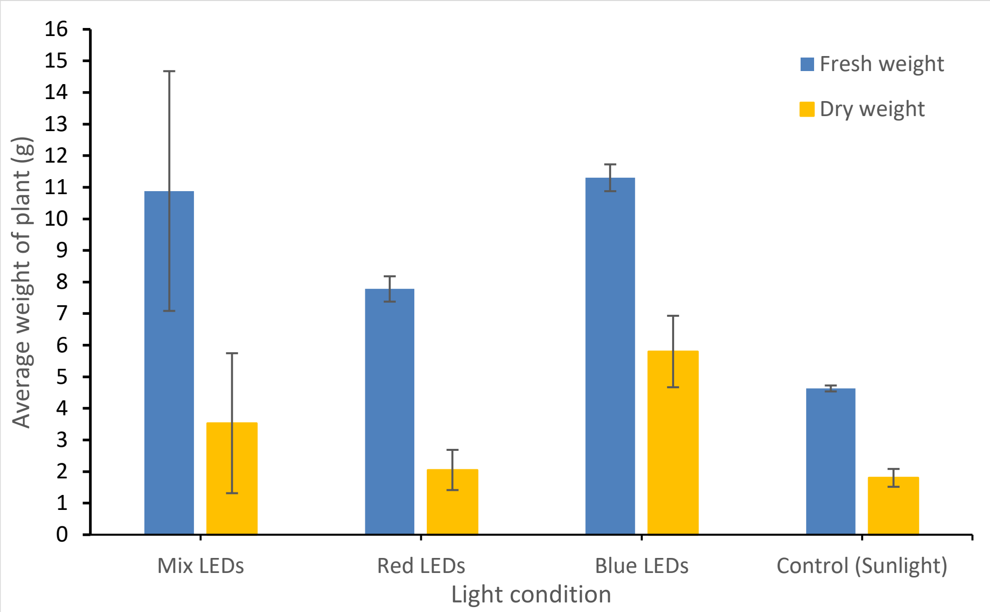

Figure 4.5: Graph of Weight of Plants Versus Light Condition for Set 1.

Similar to the trend in average height of leaves, green onions under influence of blue LEDs have the highest fresh weight as well as dry weight. To further prove that green onions under blue LEDs have the heaviest true mass, Table 4.2 was constructed to show that it has the lowest moisture content. Moisture content percentage shows a more precise measurement because it was calculated based on the difference in fresh weight and dry weight of green onions under the same light condition. Green onions under red LEDs have the highest moisture content despite dried under the same amount of heat and duration. This proves that the true mass of green onion grown in red LEDs was the lowest. Hence, true mass of green onions were in the descending order of blue LEDs, control set, mix LEDs and lastly red LEDs.

Table 4.2: Moisture Content in Green Onions in Set 1.

Condition	**Moisture Content (%)**
Mix LEDs	67.6
Red LEDs	73.7
Blue LEDs	48.7
Control (Sunlight)	61.1

4.2 Effect of Duration of Light Exposure on Growth of Green Onions

The experiment was repeated with a 6 h light exposure on the onions and was named Set 2. In this section, variables tested were similar to Set 1 and a comparison on the results will be discusses.

4.2.1 Number of Leaves

Table 4.3 shows the leaf count of green onions grown from each bulb in respective light condition when they were exposed to light for 6 h. By the end of the experiment, Red #3 and Control #1 has zero count of green onions, indicating no growth. Thus, Red #3 and Control #1 will be excluded from calculations. Other than that, to lower the standard deviation in the research, outliers such as Mix #2 and Blue #1 were removed and excluded from calculations.

Table 4.3: Average Number of Leaves Grown for Set 2.

Day	**Mix LEDs**		**Red LEDs**		**Blue LEDs**		**Control (Sun)**	
	Ave.	**S.D.**	**Ave.**	**S.D.**	**Ave.**	**S.D.**	**Ave.**	**S.D.**
1	0.0	0.00	0.5	0.71	0.5	0.71	0.0	0.00
2	1.5	0.71	3.0	2.83	0.5	0.71	1.5	0.71
3	2.0	1.41	4.0	1.41	0.5	0.71	1.5	0.71
4	2.0	1.41	4.0	1.41	2.0	1.41	2.0	1.41
5	3.0	0.00	6.5	2.12	3.0	2.83	2.0	1.41
6	4.0	0.00	10.0	2.83	3.0	2.83	3.0	2.83
7	5.0	0.00	10.0	2.83	5.0	1.41	3.0	2.83
8	5.5	0.71	10.5	3.54	8.5	0.71	3.5	2.12
9	6.5	0.71	10.5	3.54	9.5	2.12	5.5	0.71
10	6.5	0.71	10.5	3.54	11.0	4.24	5.5	0.71
11	8.0	0.00	10.5	3.54	11.0	4.24	5.5	0.71
12	8.5	0.71	10.5	3.54	11.5	3.54	6.0	0.00
13	8.5	0.71	10.5	3.54	11.5	3.54	6.0	0.00

From Set 1, Mix #2, Red #1, Blue #3 and Control #1 were excluded from calculations. On the other hand, from Set 2, Mix #2, Red #3, Blue #1 and

Control #1 were excluded from the calculation of average number of leaves tabulated in Table 4.4. Generally, plants in Set 1 have higher leaf count than those in Set 2 because onions in Set 1 have longer hours exposed to light. Other than that, Table 4.4 shows that plants grown under LEDs have more leaves than those exposed to sunlight.

Table 4.4: Average Leaf Count in Set 1 and Set 2.

	Mix LEDs	**Red LEDs**	**Blue LEDs**	**Control (Sun)**
Set 1	15.5	11.5	14.5	9.5
Set 2	8.5	10.5	11.5	6.0

4.2.2 Height of Plant

Plants were exposed to lights for 6 h daily, from 12 a.m. till 6 p.m.. Figure 4.6 and Figure 4.7 shows the growth of green onions on Day 6 and Day 13 respectively. No growth was observed in both Red #3 and Control #1. Thus, they were excluded from calculations. To reduce the standard deviation in the research, outliers such as Mix #2 and Blue #1 were removed and excluded from calculations.

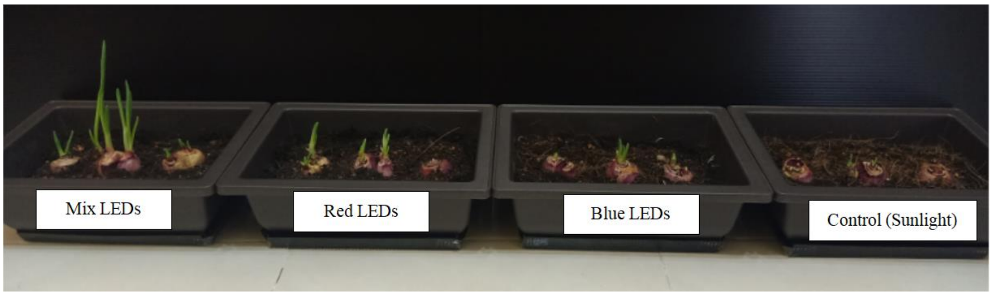

Figure 4.6: Green Onions on Day 6 of Set 2.

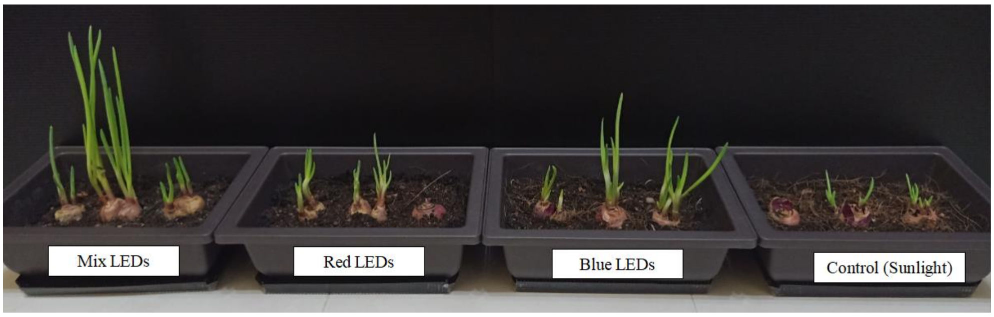

Figure 4.7: Green Onions on Day 13 of Set 2.

Figure 4.8 shows a graph of height of plants versus day that shows the growth progress of green onions throughout the experiment. Similar to Set 1, green onions exposed to blue LEDs surpass the onions in other light condition at Day 9. Onions under influence of mix LEDs and red LEDs have almost the same growth rate. Control set that was exposed to the sunlight remains as the plant that has the least growth. In conclusion, the best light to grow green onions for 13 days with light exposure duration of 6 h is blue light, followed by, either red or mixture of blue and red light and lastly, sunlight.

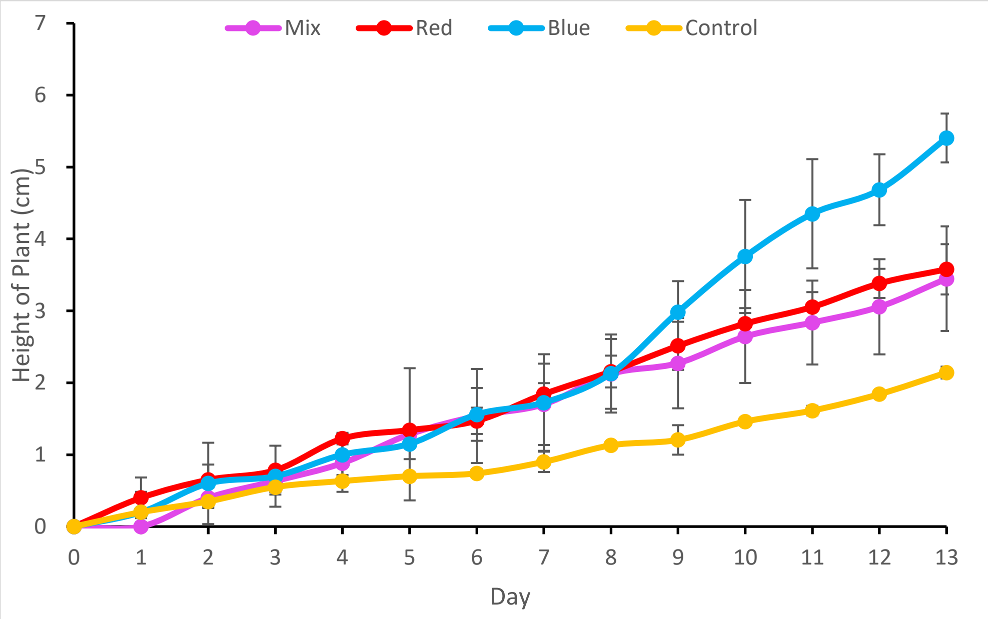

Figure 4.8: Graph of Height of Plants Versus Day for Set 2.

There is a major difference in terms of average height of plant when both sets are compared. Table 4.5 shows the comparison of average height of plants in both sets in their respective light condition. Green onions in Set 2, having 6 of light exposure, which is half of Set 1, has a decrease of more than 50% in average height of plant. In conclusion, from the perspective of average height of green onions after 13 days, the best condition for green onions to grow is under blue LEDs for 12 h.

Table 4.5: Average Height of Plants in Set 1 and Set 2.

	Mix LEDs	Red LEDs	Blue LEDs	Control (Sun)
Set 1	16.22	13.28	18.72	11.53
Set 2	3.45	3.58	5.40	2.14

4.2.3 Fresh Weight and Dry Weight of Plant

Green onions in Set 2 were treated the same way as Set 1 in heat treatment to obtain the fresh weight and dry weight. Figure 4.9 illustrates the bar graph of average weight of plants under respective light exposure condition.

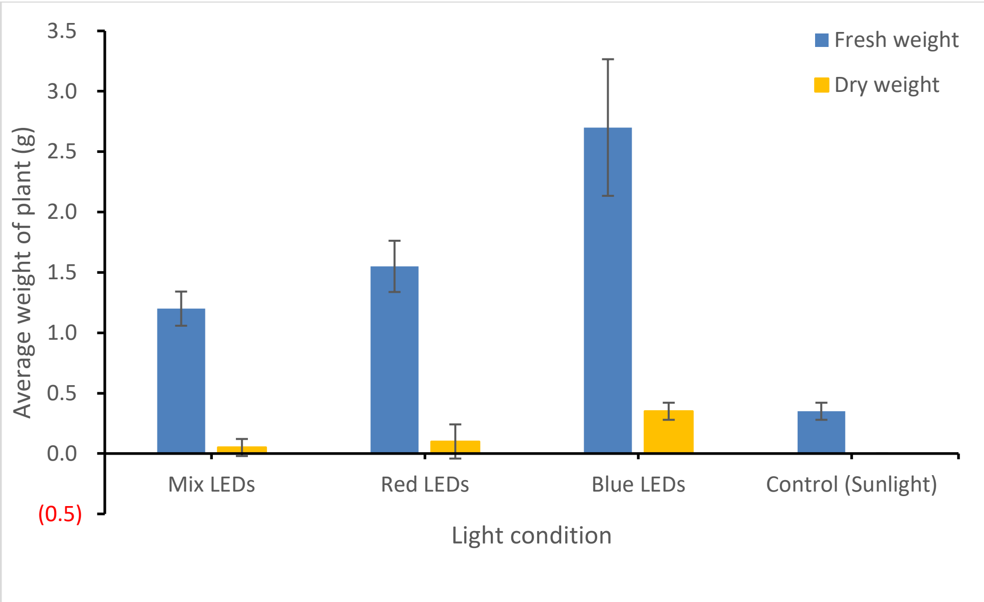

Figure 4.9: Graph of Weight of Plant Versus Light Condition for Set 2.

In Set 2, green onions grown under blue LEDs have the highest fresh weight and dry weight, similar to Set 1. Table 4.6 shows the moisture content of green onions. A higher moisture content signifies a lower true mass because most of the weight was water which had been dried when treated with heat. True mass of green onions is in the descending order of blue LEDs, red LEDs, mix LEDs and lastly control set.

Table 4.6: Moisture Content in Green Onions in Set 2.

Condition	Moisture Content (%)
Mix LEDs	95.8
Red LEDs	93.5
Blue LEDs	87.0
Control (Sunlight)	100.0

There is a major difference in terms of average fresh and dry weight of plants when both sets are compared. Table 4.7 shows the comparison of average fresh and dry weight of plants of both sets in their respective light condition. Green onions in Set 2, having 6 h of light exposure, which is half of Set 1, has a decrease of more than 50% in average fresh and dry weight. From the weight trend, it was concluded that blue light provides higher amount of nutrients for plant growth as it has the highest true mass and green onions grown for 12 h is better than 6 h.

Table 4.7: Average Fresh Weight and Dry Weight of Plants in Set 1 and Set 2.

		Mix LEDs	**Red LEDs**	**Blue LEDs**	**Control (Sun)**
Set 1	**Fresh W.**	10.88	7.78	10.03	4.69
	Dry W.	3.53	2.05	3.93	1.70
Set 2	**Fresh W.**	2.30	1.55	2.07	0.35
	Dry W.	0.17	0.10	0.23	0.00

*W. = Weight (g)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Objectives of this project were achieved. The effect of different types of LED lighting on plant growth and the applicability of LED lighting to replace sunlight to grow green onions in a mini greenhouse were studied. Furthermore, optimal duration of light exposure on the plants were also investigated. With 12 h of light exposure for 13 days, blue LEDs give the best result on the plant growth. Other than that, with 6 h of light provided for 13 days, green onions in the mixture of blue and red LEDs have the highest growth rate. However, in the perspective of weights, green onions grown under blue LEDs take the lead in both sets of 12 h and 6 h of light exposure. In conclusion, blue light is the most suitable colour of light for the growth of green onions as it provides sufficient nutrients for the growth of leaves and stems. From this research, it too proves that 12 h of light exposure is better than 6 h for the growth of green onions.

5.2 Recommendations

Upon completion of this research, several recommendations are proposed to improve future work. Onion bulbs purchased from stores should be similar in size and it would be better to plant more onions under a single light condition. Three onion bulbs were used in this setup but the deviation among individual onion in one light condition is still high as some onion bulbs are stunted. Other than that, sets that have a high difference should be repeated, if duration of the research is not a limitation. Blue and red LEDs are the common colours for growth of plants. However, to further study the impact of difference in light wavelength on plant growth, green LED can be tested as well. To determine the optimal period of light and whether the growth will be limited by the maximum hours of light, longer hours of daylight can be tested as well. The maximum daylight hours for control set, which is the sunlight would be 12 h but as for the plants under influence of LED lightings, longer hours can be investigated.

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APPENDIX

Appendix A.1: Number of Leaves Grown from Each Onion Bulb for Set 1.

Day	Mix LEDs			Red LEDs			Blue LEDs			Control (Sun)		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
1	5	1	9	2	7	8	8	1	4	8	6	4
2	6	1	11	2	7	9	12	3	4	8	6	4
3	7	1	12	3	7	10	13	4	5	9	9	6
4	7	1	14	3	8	12	15	5	6	11	9	7
5	10	2	15	3	9	12	16	5	6	11	9	8
6	10	2	16	3	9	12	18	5	8	12	9	9
7	11	2	17	3	10	12	18	7	8	14	9	9
8	11	3	17	4	10	12	19	7	8	14	10	9
9	13	3	17	4	10	12	21	7	8	14	10	9
10	13	3	17	4	10	12	21	7	8	14	10	9
11	13	3	18	4	10	13	21	8	8	14	10	9
12	13	3	18	5	10	13	21	8	8	14	10	9
13	13	3	18	5	10	13	21	8	8	14	10	9

Appendix A.2: Number of Leaves Grown from Each Onion Bulb for Set 2.

Day	Mix LEDs			Red LEDs			Blue LEDs			Control (Sun)		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
1	0	2	0	1	0	0	0	1	0	0	0	0
2	2	6	1	1	5	0	0	1	0	0	2	1
3	3	10	1	3	5	0	0	1	0	0	2	1
4	3	11	1	3	5	0	1	3	1	0	3	1
5	3	11	3	5	8	0	1	5	1	0	3	1
6	4	11	4	8	12	0	1	5	1	0	5	1
7	5	12	5	8	12	0	1	6	4	0	5	1
8	6	13	5	8	13	0	2	8	9	0	5	2
9	6	13	7	8	13	0	3	8	11	0	6	5
10	6	13	7	8	13	0	3	8	14	0	6	5
11	8	13	8	8	13	0	5	8	14	0	6	5
12	8	13	9	8	13	0	6	9	14	0	6	6
13	8	13	9	8	13	0	6	9	14	0	6	6

Appendix B.1: Height of Individual Green Onions in Set 1.

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
1	Mix LEDs	#1	1.0 0.5 1.4 1.0 1.0	0.98	0.94
		#2	0.3	0.30	
		#3	0.3 1.1 1.2 1.1 0.9 0.9 1.2 1.1 0.3	0.90	
	Red LEDs	#1	0.2 0.2	0.20	1.00
		#2	0.6 0.6 0.7 0.7 0.7 0.6 0.6	0.64	
		#3	1.0 2.0 1.2 1.0 1.0 1.0 1.7 2.0	1.36	
	Blue LEDs	#1	2.0 1.0 1.2 2.0 1.0 0.4 0.3 0.4	1.04	1.02
		#2	1.0	1.00	
		#3	1.0 1.0 1.0 1.2	1.05	
	Control (Sunlight)	#1	0.6 0.8 1.2 0.8 0.5 0.3 0.4 0.4	0.63	0.74
		#2	0.6 2.1 0.6 0.5 1.0 1.2	1.00	
		#3	0.6 0.6 0.4 0.3	0.48	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
2	Mix LEDs	#1	1.4 3.0 2.1 3.5 2.2 2.2	2.40	2.86
		#2	0.6	0.60	
		#3	2.9 2.9 2.0 2.5 4.5 3.8 3.6 3.0 4.0 4.1 3.2	3.32	
	Red LEDs	#1	0.4 0.4	0.40	2.00
		#2	1.2 1.2 1.3 1.3 1.2 0.9 0.8	1.13	
		#3	2.4 4.7 2.5 2.0 2.6 2.6 2.5 3.0 3.5	2.87	
	Blue LEDs	#1	3.0 2.0 1.5 3.5 3.0 3.1 2.0 2.5 3.5 3.2 2.6 4.4	2.86	2.30
		#2	0.6 2.0 2.6	1.73	
		#3	2.2 2.0 1.0 1.0	1.55	
	Control (Sunlight)	#1	3.1 1.2 1.7 1.5 1.0 1.8 1.7 1.0	1.63	1.25
		#2	4.0 1.2 1.0 0.7 2.0 2.3 0.7 0.7 0.7	1.48	
		#3	1.0 1.2 0.7 0.7 1.5	1.02	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
3	Mix LEDs	#1	2.7 5.2 3.0 5.5 4.1 3.5 4.2	4.03	4.79
		#2	1.0	1.00	
		#3	6.5 6.5 4.6 5.5 5.5 6.0 7.5 4.5 6.0 5.1 5.0 4.0	5.56	
	Red LEDs	#1	0.8 0.8 0.5	0.70	3.40
		#2	2.7 1.8 2.5 3.0 1.9 2.0 1.6	2.21	
		#3	7.9 4.4 6.0 4.5 3.3 2.5 4.5 5.2 4.0 3.5	4.58	
	Blue LEDs	#1	3.5 5.5 3.6 6.2 6.0 4.0 4.5 7.2 4.5 5.0 5.2 6.2 6.5	5.22	3.95
		#2	1.5 1.5 3.0 4.7	2.68	
		#3	4.0 3.3 1.5 1.7 2.5	2.60	
	Control (Sunlight)	#1	5.7 2.6 2.0 1.2 2.9 2.9 2.0 3.7 3.7	2.97	2.53
		#2	2.5 1.5 6.0 1.0 4.2 0.8 5.0 3.5 2.5	3.00	
		#3	2.0 3.5 2.7 1.7 1.7 0.7	2.05	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)															Average Height (cm)	
4	Mix LEDs	#1	4.6	5.2	8.0	6.2	7.4	4.5	6.0									5.99	6.44
		#2	1.4															1.40	
		#3	7.0	6.4	8.3	8.3	6.4	2.5	6.4	6.5	7.5	6.7	10.4	8.3	7.9	4.0		6.90	
	Red LEDs	#1	1.0	1.2	1.0													1.07	4.92
		#2	5.1	3.1	2.1	3.4	5.4	4.0	3.4	2.5								3.63	
		#3	11.0	6.5	4.0	4.9	6.0	7.5	8.9	6.0	4.5	4.2	4.4	6.7				6.22	
	Blue LEDs	#1	6.0	8.0	4.2	5.2	9.8	9.0	7.0	6.5	8.6	8.6	8.5	6.2	5.4	10.5	8.5	7.47	5.98
		#2	4.4	1.8	4.0	4.5	7.8											4.50	
		#3	2.0	2.0	1.2	6.7	4.7	4.2										3.47	
	Control (Sunlight)	#1	4.1	8.2	2.4	3.2	4.5	1.5	3.8	5.7	2.5	4.5	2.0					3.85	4.07
		#2	1.7	4.5	8.0	6.7	1.0	0.8	4.2	4.5	7.8							4.36	
		#3	5.5	2.4	2.7	2.2	2.7	5.0	6.0									3.79	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
5	Mix LEDs	#1	6.5 3.0 7.4 10.5 8.0 9.0 7.6 4.5 4.0 5.3	6.58	7.60
		#2	1.5 1.5	1.50	
		#3	8.7 4.0 10.1 8.4 8.5 10.2 8.0 9.0 10.0 9.5 3.5 13.0 9.6 10.5 6.4	8.63	
	Red LEDs	#1	1.4 1.5 1.2	1.37	6.29
		#2	7.0 4.2 2.4 4.5 7.5 4.0 6.0 3.5 4.9	4.89	
		#3	8.0 5.5 4.0 9.2 7.4 5.4 13.5 5.0 8.5 6.4 7.8 11.5	7.68	
	Blue LEDs	#1	4.7 8.3 13.1 8.3 10.2 12.4 10.0 6.5 7.8 6.5 14.0 10.5 8.5 12.0 11.5 8.4	9.54	8.21
		#2	3.6 7.5 4.2 8.1 11.0	6.88	
		#3	2.5 2.0 2.5 5.0 7.0 10.1	4.85	
	Control (Sunlight)	#1	6.7 4.0 2.5 5.2 5.0 10.0 3.0 4.0 5.0 1.5 4.4	4.66	5.60
		#2	9.0 2.5 9.8 1.7 5.0 6.5 6.2 10.4 2.0	5.90	
		#3	8.1 4.0 3.2 4.9 2.5 8.0 7.5 4.2	5.30	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
6	Mix LEDs	#1	8.5 4.5 10.4 13.7 10.5 7.4 6.4 6.0 10.2 9.9	8.75	9.35
		#2	1.5 1.5	1.50	
		#3	11.9 9.9 9.0 11.4 5.4 10.4 8.5 11.0 5.5 12.0 12.5 8.0 10.5 12.0 5.6 15.7	9.96	
	Red LEDs	#1	1.6 1.7 2.0	1.77	7.76
		#2	5.4 8.9 5.0 5.0 8.9 6.7 5.0 7.5 5.2	6.40	
		#3	15.0 6.3 9.8 9.0 8.5 13.6 6.0 9.0 11.0 9.7 7.0 4.5	9.12	
	Blue LEDs	#1	10.7 4.7 16.0 10.2 12.2 15.0 8.7 12.5 8.5 16.5 14.7 11.5 14.5 10.5 13.9 7.0 9.2 7.5	11.32	10.30
		#2	6.2 10.5 4.5 11.2 14.0	9.28	
		#3	4.0 3.6 2.5 2.5 5.5 9.7 12.7 5.0	5.69	
	Control (Sunlight)	#1	11.2 5.9 5.0 6.5 1.2 2.0 5.5 3.2 6.7 3.7 8.2 5.2	5.36	6.67
		#2	2.1 2.2 7.7 12.2 7.9 5.0 10.6 10.2 3.9	6.87	
		#3	11.0 6.2 9.0 10.4 5.5 3.6 3.0 2.5 7.0	6.47	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
7	Mix LEDs	#1	11.4 7.4 11.0 8.0 8.2 9.9 13.2 16.8 13.6 6.5 10.6	10.60	10.87
		#2	1.9 2.2	2.05	
		#3	13.2 11.4 9.5 12.1 6.5 11.5 8.8 13.0 7.0 13.5 10.6 9.5 13.5 13.5 7.0 15.9 13.0	11.15	
	Red LEDs	#1	2.0 2.1 2.0	2.03	8.83
		#2	6.5 10.5 5.5 6.4 10.5 3.0 6.2 9.5 6.2 8.5	7.28	
		#3	10.0 10.5 15.8 16.8 8.0 11.6 6.0 10.2 12.7 11.0 8.0 4.0	10.38	
	Blue LEDs	#1	12.2 13.6 5.0 18.1 13.2 9.0 14.3 10.5 17.4 17.7 9.4 18.5 10.3 9.5 16.8 17.0 12.6 11.9	13.17	11.45
		#2	9.0 13.5 1.7 4.5 15.1 8.2 16.2	9.74	
		#3	15.1 7.0 12.6 5.9 4.8 6.0 3.0 3.6	7.25	
	Control (Sunlight)	#1	6.5 12.5 3.5 5.4 7.5 2.0 2.6 6.5 4.0 9.6 3.0 6.5 4.2 7.5	5.81	8.09
		#2	2.0 2.5 14.0 9.0 10.5 6.0 11.6 4.6 12.7	8.10	
		#3	12.5 7.2 4.6 13.6 8.5 10.1 3.4 3.7 9.2	8.09	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
8	Mix LEDs	#1	8.5 13.1 16.4 18.6 14.6 11.6 9.0 8.1 13.1 8.9 11.0	12.08	11.89
		#2	2.0 2.0 2.5	2.17	
		#3	14.3 5.4 12.4 9.5 12.2 12.4 7.4 8.9 14.4 14.8 8.1 15.1 11.1 11.0 15.6 17.1 9.0	11.69	
	Red LEDs	#1	0.7 2.0 2.5 2.1	1.83	9.86
		#2	7.5 12.0 5.5 7.0 11.6 10.2 8.0 3.2 7.5 11.9	8.44	
		#3	13.0 9.2 18.2 10.5 12.2 17.0 14.0 11.6 6.0 10.4 9.2 4.0	11.28	
	Blue LEDs	#1	4.7 15.0 19.6 14.0 14.4 19.1 12.6 16.0 9.0 11.8 19.7 20.5 12.1 14.5 11.5 19.5 19.1 11.8 10.5	14.49	13.15
		#2	12.0 16.5 1.9 4.5 18.3 10.8 18.7	11.81	
		#3	6.2 16.5 9.0 15.7 5.5 3.0 5.2 8.9	8.75	
	Control (Sunlight)	#1	3.3 6.0 8.4 7.0 13.1 2.5 3.0 4.5 7.4 10.5 3.5 7.0 5.4 8.7	6.45	8.81
		#2	9.7 3.0 2.4 12.1 5.6 14.5 15.0 2.9 11.6 6.4	8.32	
		#3	13.8 8.2 4.3 16.1 10.5 11.2 11.0 5.0 3.6	9.30	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
9	Mix LEDs	#1	11.4 11.3 15.5 7.4 19.4 20.7 11.1 15.9 8.4 10.4 13.8 6.8 16.4	12.96	12.80
		#2	1.9 2.2 2.9	2.33	
		#3	15.2 6.1 13.5 10.0 13.1 8.1 12.6 9.0 15.8 9.5 16.1 11.4 12.5 16.5 10.5 17.6 17.4	12.64	
	Red LEDs	#1	1.5 2.5 2.6 3.1	2.43	11.04
		#2	8.4 13.6 5.6 8.0 13.2 12.0 9.5 8.6 13.5 3.5	9.59	
		#3	19.4 14.4 10.6 6.2 13.1 15.7 13.6 10.5 4.5 10.2 13.5 18.2	12.49	
	Blue LEDs	#1	5.0 17.0 20.7 16.5 9.0 15.1 21.2 14.6 18.0 9.5 7.7 23.5 13.8 21.0 12.2 16.4 13.5 11.0 14.4 21.5 21.2	15.37	14.87
		#2	14.9 18.8 1.9 13.5 9.5 19.8 22.2	14.37	
		#3	6.6 7.6 11.5 6.6 18.2 17.9 11.0 3.6	10.38	
	Control (Sunlight)	#1	3.5 9.1 6.0 2.5 2.5 7.6 14.0 5.4 8.3 11.4 3.6 7.5 6.2 9.5	6.94	9.96
		#2	2.5 3.2 10.4 12.5 6.5 15.7 15.8 3.4 13.2 6.8	9.00	
		#3	18.2 12.4 11.6 9.2 15.2 4.6 3.4 6.0 12.2	10.31	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
10	Mix LEDs	#1	12.5 17.0 20.3 8.5 22.0 17.0 12.8 11.9 17.0 7.6 15.1 11.1 8.5	13.95	13.49
		#2	1.9 2.2 2.9	2.33	
		#3	15.5 6.2 13.9 10.0 8.5 13.5 13.0 9.0 16.7 10.4 16.9 16.5 11.0 13.0 18.3 11.5 17.8	13.04	
	Red LEDs	#1	1.7 2.6 2.9 3.3	2.63	11.83
		#2	8.6 14.5 6.4 8.5 14.4 12.7 10.2 3.7 9.5 16.9	10.54	
		#3	10.8 14.4 19.0 20.3 11.6 15.0 6.1 13.8 16.7 14.0 11.1 4.6	13.12	
	Blue LEDs	#1	5.0 17.8 21.5 17.5 10.0 15.2 9.5 8.0 18.7 15.7 15.1 21.2 24.8 12.2 17.2 14.6 22.6 15.3 11.0 21.7 19.0	15.89	15.19
		#2	16.5 19.7 1.5 4.5 15.5 20.2 23.6	14.50	
		#3	6.5 8.6 12.6 7.0 18.0 11.6 19.2 4.0	10.94	
	Control (Sunlight)	#1	3.5 6.5 9.2 7.8 14.0 3.8 3.7 5.5 8.5 6.1 9.1 11.5 7.6 4.5	7.24	10.12
		#2	10.5 3.2 2.4 16.1 4.4 14.5 7.4 12.5 7.0 16.3	9.43	
		#3	11.6 13.5 19.4 15.6 9.6 4.5 3.6 6.5 12.9	10.80	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
11	Mix LEDs	#1	14.0 17.6 10.4 19.0 20.0 18.2 14.4 11.5 8.5 12.0 16.3 17.8 9.4	14.55	13.95
		#2	1.9 2.5 3.0	2.47	
		#3	16.0 9.0 14.3 9.7 9.0 13.0 14.0 9.5 17.7 17.2 11.2 6.1 11.5 14.2 17.6 12.7 18.0 19.8	13.36	
	Red LEDs	#1	1.9 2.6 2.9 3.6	2.75	12.04
		#2	9.6 15.7 6.0 8.5 14.7 13.4 11.1 10.9 18.8 4.0	11.27	
		#3	12.5 15.0 21.1 10.6 15.0 19.7 6.2 14.5 17.6 14.6 11.6 4.9 3.2	12.81	
	Blue LEDs	#1	4.9 21.7 18.9 11.1 15.5 19.2 9.0 17.0 19.7 22.1 8.8 12.1 15.8 18.0 23.2 23.4 11.1 17.1 16.9 21.4 26.4	16.82	16.39
		#2	18.0 20.2 9.0 1.9 13.1 17.8 21.0 26.7	15.96	
		#3	7.1 13.6 18.6 21.0 6.6 4.0 10.9 14.2	12.00	
	Control (Sunlight)	#1	3.5 7.0 9.7 4.6 3.8 8.0 14.0 9.0 6.5 7.0 9.7 11.9 4.2 8.1	7.64	10.66
		#2	10.7 3.6 2.6 12.5 7.6 16.5 7.2 16.8 4.5 17.0	9.90	
		#3	5.2 10.5 16.5 11.7 14.3 20.2 13.7 7.0 3.7	11.42	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
12	Mix LEDs	#1	18.0 16.1 12.0 12.6 20.0 23.7 15.5 18.6 18.1 10.6 18.0 13.5 8.8	15.81	15.00
		#2	2.0 3.5 3.9	3.13	
		#3	16.8 10.0 15.1 10.0 13.0 11.0 14.5 11.5 15.0 6.8 18.3 11.0 19.0 12.2 18.0 18.1 14.0 21.1	14.19	
	Red LEDs	#1	2.0 3.0 3.0 4.4 2.6	3.00	12.70
		#2	16.5 6.0 15.6 13.9 12.2 4.0 12.6 20.6 10.0 9.0	12.04	
		#3	20.4 15.6 11.0 15.1 13.5 22.0 6.1 15.1 4.6 18.1 5.0 12.0 15.2	13.36	
	Blue LEDs	#1	12.5 15.6 21.0 5.1 20.0 22.2 9.1 21.0 19.1 22.8 18.5 21.6 27.8 19.2 17.2 24.0 11.1 18.1 24.0 18.1 27.4	18.83	18.16
		#2	20.5 10.5 21.5 15.2 20.0 21.5 29.0 1.8	17.50	
		#3	7.1 15.7 19.2 22.0 7.3 5.2 14.3 15.2	13.25	
	Control (Sunlight)	#1	7.8 10.5 5.5 4.2 8.4 14.0 9.7 7.5 5.6 9.3 12.4 8.0 10.0 4.2	8.36	11.32
		#2	18.3 3.6 2.6 12.7 8.0 16.9 5.0 7.2 17.2 17.0	10.85	
		#3	12.0 15.0 20.5 16.9 11.0 5.1 4.0 7.5 14.1	11.79	

Appendix B.1: Height of Individual Green Onions in Set 1. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
13	Mix LEDs	#1	20.2 17.2 12.0 14.6 20.0 22.0 16.2 19.1 18.6 12.2 19.7 20.0 9.0	16.98	16.22
		#2	2.0 3.2 3.8	3.00	
		#3	17.1 13.0 15.5 13.0 14.0 15.0 13.0 13.0 13.0 19.5 18.1 11.5 15.6 13.0 18.7 18.2 15.0 22.1	15.46	
	Red LEDs	#1	2.1 3.4 3.1 5.1 3.0	3.34	13.28
		#2	6.2 9.6 16.5 11.5 17.4 14.1 13.4 21.0 4.0 14.0	12.77	
		#3	20.5 16.0 11.0 15.0 14.5 22.6 6.1 16.0 5.2 19.4 15.5 12.5 5.0	13.79	
	Blue LEDs	#1	15.7 13.6 10.5 22.4 21.0 22.5 9.1 11.1 22.5 20.5 23.0 19.9 21.5 29.0 12.2 18.8 20.5 24.6 11.0 19.5 24.5	18.73	18.72
		#2	11.5 22.0 22.1 1.7 17.3 21.7 22.2 31.2	18.71	
		#3	7.0 19.5 19.0 23.5 7.1 6.2 16.0 16.0	14.29	
	Control (Sunlight)	#1	10.3 8.0 3.6 8.8 14.1 5.9 4.4 10.0 8.0 10.0 8.0 12.4 5.1 9.5	8.44	11.53
		#2	18.4 4.0 2.6 12.7 8.5 17.0 7.4 17.7 5.6 17.3	11.12	
		#3	12.0 15.2 20.9 17.0 11.1 5.2 4.1 7.6 14.4	11.94	

Appendix B.2: Height of Individual Green Onions in Set 2.

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
1	Mix LEDs	#1	-	0.00	0.00
		#2	0.6 0.4	0.50	
		#3	-	0.00	
	Red LEDs	#1	0.4	0.40	0.40
		#2	-	0.00	
		#3	-	0.00	
	Blue LEDs	#1	-	0.00	0.20
		#2	0.4	0.40	
		#3	-	0.00	
	Control (Sunlight)	#1	-	0.00	0.20
		#2	-	0.00	
		#3	0.2	0.20	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
2	Mix LEDs	#1	0.5 0.5	0.50	0.40
		#2	0.6 1.0 2.0 2.0 0.8 0.8	1.20	
		#3	0.3	0.30	
	Red LEDs	#1	0.8	0.80	0.65
		#2	0.5 0.5 0.5 0.5 0.5	0.50	
		#3	-	0.00	
	Blue LEDs	#1	-	0.00	0.60
		#2	1.0	1.00	
		#3	0.2	0.20	
	Control (Sunlight)	#1	-	0.00	0.35
		#2	0.3 0.3	0.30	
		#3	0.4	0.40	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
3	Mix LEDs	#1	0.7 1.0 0.6	0.77	0.63
		#2	1.1 2.5 3.0 4.0 1.5 1.5 2.3 2.5 0.8 1.0	2.02	
		#3	0.5	0.50	
	Red LEDs	#1	0.2 1.5 0.6	0.77	0.78
		#2	0.5 1.0 1.2 0.8 0.5	0.80	
		#3	-	0.00	
	Blue LEDs	#1	-	0.00	0.70
		#2	1.0	1.00	
		#3	0.4	0.40	
	Control (Sunlight)	#1	-	0.00	0.55
		#2	0.6 0.6	0.60	
		#3	0.5	0.50	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
4	Mix LEDs	#1	1.0 1.3 1.2	1.17	0.88
		#2	1.4 3.7 3.5 3.0 3.0 6.5 1.7 3.0 1.5 4.5 4.5	3.30	
		#3	0.6	0.60	
	Red LEDs	#1	2.5 0.4 0.6	1.17	1.22
		#2	1.2 2.0 1.5 0.7 1.0	1.28	
		#3	-	0.00	
	Blue LEDs	#1	0.3	0.30	1.00
		#2	1.0 1.4 1.2	1.20	
		#3	0.8	0.80	
	Control (Sunlight)	#1	-	0.00	0.63
		#2	0.5 0.9 0.6	0.67	
		#3	0.6	0.60	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
5	Mix LEDs	#1	1.5 2.1 2.2	1.93	1.28
		#2	2.1 5.2 9.0 4.2 4.6 4.4 5.4 3.4 4.7 6.0 2.8	4.71	
		#3	0.6 0.8 0.5	0.63	
	Red LEDs	#1	1.2 0.5 3.0 0.7 1.2	1.32	1.34
		#2	0.7 1.2 0.8 2.0 2.5 2.0 0.9 0.8	1.36	
		#3	-	0.00	
	Blue LEDs	#1	0.4	0.40	1.15
		#2	1.5 0.6 1.0 2.0 1.4	1.30	
		#3	1.0	1.00	
	Control (Sunlight)	#1	-	0.00	0.70
		#2	0.6 1.0 0.5	0.70	
		#3	0.7	0.70	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
6	Mix LEDs	#1	2.6 2.7 2.0 0.7	2.00	1.54
		#2	3.0 6.6 4.1 5.3 5.2 10.3 3.5 4.2 6.2 6.7 5.7	5.53	
		#3	1.2 0.9 1.3 0.9	1.08	
	Red LEDs	#1	1.7 1.1 1.1 0.7 1.4 2.5 3.6 0.7	1.60	1.47
		#2	1.1 2.2 2.0 2.5 2.5 1.1 0.9 1.5 0.6 0.7 0.5 0.5	1.34	
		#3	-	0.00	
	Blue LEDs	#1	0.6	0.60	1.56
		#2	2.0 1.2 1.5 2.5 1.9	1.82	
		#3	1.3	1.30	
	Control (Sunlight)	#1	-	0.00	0.74
		#2	1.0 0.6 1.3 0.5 0.5	0.78	
		#3	0.7	0.70	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
7	Mix LEDs	#1	3.4 1.3 0.8 2.0 3.0	2.10	1.70
		#2	4.6 8.0 4.5 6.6 6.4 12.1 6.8 6.8 6.0 8.0 5.0 1.4	6.35	
		#3	1.6 0.7 1.6 1.5 1.1	1.30	
	Red LEDs	#1	2.6 1.5 1.5 0.6 2.6 4.2 0.6 2.0	1.95	1.84
		#2	1.5 2.8 2.9 3.5 2.5 1.5 1.0 2.0 1.0 1.0 0.5 0.6	1.73	
		#3	-	0.00	
	Blue LEDs	#1	1.0	1.00	1.73
		#2	0.6 3.0 2.0 2.1 3.0 2.5	2.20	
		#3	1.3 1.4 1.7 0.6	1.25	
	Control (Sunlight)	#1	-	0.00	0.90
		#2	1.4 0.8 1.6 0.6 0.6	1.00	
		#3	0.8	0.80	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
8	Mix LEDs	#1	1.1 1.6 4.0 2.5 2.0 3.6	2.47	2.12
		#2	7.1 8.7 4.7 2.6 8.8 8.5 13.6 6.6 8.9 8.4 7.3 7.3 1.6	7.24	
		#3	1.7 2.0 2.0 2.1 1.1	1.78	
	Red LEDs	#1	3.0 2.0 1.9 0.6 3.0 4.5 2.5 1.0	2.31	2.16
		#2	2.0 3.2 3.0 3.9 3.1 1.8 0.9 2.5 1.4 1.4 1.1 0.8 0.9	2.00	
		#3	-	0.00	
	Blue LEDs	#1	1.3 0.9	1.10	2.13
		#2	2.5 4.4 1.2 1.0 1.0 3.0 4.0 3.0	2.51	
		#3	1.7 1.7 2.6 1.4 1.5 1.4 1.2 2.1 2.1	1.74	
	Control (Sunlight)	#1	-	0.00	1.13
		#2	0.9 1.7 1.6 0.8 0.8	1.16	
		#3	1.2 1.0	1.10	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
9	Mix LEDs	#1	2.7 4.0 2.1 4.9 1.1 1.5	2.72	2.27
		#2	10.0 9.9 4.5 3.6 11.0 10.5 14.5 8.9 7.5 9.7 9.0 9.4 2.4	8.53	
		#3	2.5 1.4 1.1 0.8 2.5 2.4 2.1	1.83	
	Red LEDs	#1	3.5 2.5 2.2 0.7 5.1 4.0 2.9 1.1	2.75	2.51
		#2	1.5 1.2 1.4 1.7 1.9 2.8 2.0 3.5 2.7 3.1 4.5 1.7 1.6	2.28	
		#3	-	0.00	
	Blue LEDs	#1	1.5 1.5 1.2	1.40	2.98
		#2	6.2 3.7 1.5 1.5 1.5 3.5 3.7 4.7	3.29	
		#3	3.6 3.2 2.2 3.4 1.6 3.2 1.6 2.0 3.1 2.7 2.9	2.68	
	Control (Sunlight)	#1	-	0.00	1.21
		#2	1.9 1.1 1.2 0.6 1.2 2.1	1.35	
		#3	0.9 1.5 0.9 1.2 0.8	1.06	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
10	Mix LEDs	#1	2.6 6.2 2.7 4.0 1.9 1.2	3.10	2.64
		#2	10.0 12.3 5.0 5.0 13.0 13.3 15.6 7.7 11.5 9.5 11.5 3.5 10.3	9.86	
		#3	3.0 1.8 1.2 1.3 3.0 2.0 3.0	2.19	
	Red LEDs	#1	3.9 2.8 2.4 3.5 5.0 3.5 1.5 1.2	2.98	2.82
		#2	2.5 3.9 3.0 3.7 5.1 2.4 1.0 2.0 1.5 3.5 2.5 2.1 1.5	2.67	
		#3	-	0.00	
	Blue LEDs	#1	2.2 2.1 1.2	1.83	3.76
		#2	4.7 8.1 1.8 2.5 2.3 4.4 5.5 5.2	4.31	
		#3	4.5 4.2 5.0 3.2 2.0 2.5 5.0 2.0 2.3 2.7 3.2 3.2 3.5 1.5	3.20	
	Control (Sunlight)	#1	-	0.00	1.46
		#2	2.0 1.0 1.2 1.0 1.2 2.6	1.50	
		#3	2.1 1.3 1.4 1.3 1.0	1.42	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
11	Mix LEDs	#1	3.0 7.0 2.8 2.5 5.0 2.5 1.7 1.5	3.25	2.84
		#2	13.6 10.2 4.5 5.5 14.3 14.6 16.0 7.5 12.2 10.0 12.8 10.0 4.2	10.42	
		#3	3.6 2.2 1.0 1.8 3.5 3.0 2.2 2.1	2.43	
	Red LEDs	#1	4.0 3.0 2.6 1.0 5.5 4.0 1.5 4.0	3.20	3.05
		#2	2.5 3.9 3.0 4.0 5.6 2.7 1.3 3.6 1.8 2.5 2.6 2.3 2.0	2.91	
		#3	-	0.00	
	Blue LEDs	#1	3.0 2.9 1.9 0.8 1.0	1.92	4.35
		#2	5.4 9.4 2.2 3.0 2.4 4.7 6.0 6.0	4.89	
		#3	4.7 4.5 3.2 6.4 3.0 7.0 2.3 3.3 4.2 4.2 3.5 4.5 1.6 1.0	3.81	
	Control (Sunlight)	#1	-	0.00	1.61
		#2	1.2 1.0 1.2 2.8 2.2 1.0	1.57	
		#3	2.4 1.6 1.8 1.3 1.2	1.66	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
12	Mix LEDs	#1	5.4 2.8 2.9 3.2 7.7 1.3 1.9 3.0	3.53	3.06
		#2	6.7 15.7 16.2 15.2 10.5 15.0 7.6 13.4 9.8 13.5 3.0 11.0 5.0	10.97	
		#3	4.2 2.5 1.3 1.1 2.2 4.0 3.5 2.1 2.4	2.59	
	Red LEDs	#1	4.2 3.1 2.7 1.5 5.7 4.5 5.0 1.5	3.53	3.38
		#2	2.7 2.1 2.2 3.0 4.1 2.5 3.1 1.5 6.3 4.4 3.2 4.0 3.0	3.24	
		#3	-	0.00	
	Blue LEDs	#1	2.4 1.5 1.1 3.5 3.7 1.5	2.28	4.68
		#2	6.1 7.2 2.3 10.4 6.2 2.5 3.4 5.3 1.9	5.03	
		#3	8.6 3.5 3.5 3.5 8.4 5.5 4.5 2.2 2.3 3.6 4.5 5.3 1.8 3.5	4.34	
	Control (Sunlight)	#1	-	0.00	1.84
		#2	1.6 1.2 3.1 1.5 2.6 1.0	1.83	
		#3	2.9 1.0 2.0 2.2 1.5 1.5	1.85	

Appendix B.2: Height of Individual Green Onions in Set 2. (cont.)

Day	Light Condition		Height of Leaves (cm)	Average Height (cm)	
13	Mix LEDs	#1	3.0 3.0 6.0 3.5 8.4 3.6 2.5 1.7	3.96	3.45
		#2	7.7 16.8 16.7 16.3 15.8 10.4 7.6 13.7 10.0 14.3 3.4 11.2 6.0	11.53	
		#3	2.5 1.3 4.8 2.9 1.5 3.9 4.3 2.6 2.6	2.93	
	Red LEDs	#1	1.5 2.6 3.7 4.5 2.0 5.9 6.0 4.4	3.83	3.58
		#2	2.7 2.3 2.3 3.3 4.2 2.7 1.4 3.3 4.2 4.8 6.7 3.5 1.9	3.33	
		#3	-	0.00	
	Blue LEDs	#1	2.9 2.0 4.3 4.9 1.6 1.6	2.88	5.40
		#2	6.6 8.5 2.6 7.1 11.2 2.4 3.8 2.7 5.9	5.64	
		#3	6.7 4.8 3.6 4.1 10.0 4.0 10.0 2.3 2.4 4.0 5.0 5.0 5.9 4.5	5.16	
	Control (Sunlight)	#1	-	0.00	2.14
		#2	2.0 2.0 4.0 1.2 3.0 1.0	2.20	
		#3	3.3 1.4 2.1 2.5 1.6 1.6	2.08	

Appendix B.3: Average Height of Green Onions in Set 1.

Day	Mix LEDs				Red LEDs				Blue LEDs				Control (Sun)			
	#1	#2	#3	Ave.	#1	#2	#3	Ave.	#1	#2	#3	Ave.	#1	#2	#3	Ave.
1	0.98	0.30	0.90	0.94	0.20	0.64	1.36	1.00	1.04	1.00	1.05	1.03	0.63	1.00	0.48	0.70
2	2.40	0.60	3.32	2.86	0.40	1.13	2.87	2.00	2.86	1.73	1.55	2.05	1.63	1.48	1.02	1.37
3	4.03	1.00	5.56	4.79	0.70	2.21	4.58	3.40	5.22	2.68	2.60	3.50	2.97	3.00	2.05	2.67
4	5.99	1.40	6.90	6.44	1.07	3.63	6.22	4.92	7.47	4.50	3.47	5.14	3.85	4.36	3.79	4.00
5	6.58	1.50	8.63	7.60	1.37	4.89	7.68	6.29	9.54	6.88	4.85	7.09	4.66	5.90	5.30	5.29
6	8.75	1.50	9.96	9.35	1.77	6.40	9.12	7.76	11.32	9.28	5.69	8.76	5.36	6.87	6.47	6.23
7	10.60	2.05	11.15	10.87	2.03	7.28	10.38	8.83	13.17	9.74	7.25	10.05	5.81	8.10	8.09	7.33
8	12.08	2.17	11.69	11.89	1.83	8.44	11.28	9.86	14.49	11.81	8.75	11.69	6.45	8.32	9.30	8.02
9	12.96	2.33	12.64	12.80	2.43	9.59	12.49	11.04	15.37	14.37	10.38	13.37	6.94	9.00	10.31	8.75
10	13.95	2.33	13.04	13.49	2.63	10.54	13.12	11.83	15.89	14.50	10.94	13.77	7.24	9.43	10.80	9.16
11	15.05	2.47	13.20	14.12	2.75	11.27	12.81	12.04	16.82	15.96	12.00	14.93	7.64	9.90	11.42	9.66
12	16.26	3.13	13.87	15.07	3.00	12.04	13.36	12.70	18.83	17.50	13.25	16.53	8.36	10.85	11.79	10.33
13	17.98	3.00	14.27	16.13	3.34	12.77	13.79	13.28	18.73	18.71	14.29	17.24	8.44	11.12	11.94	10.50

*Ave. = Average value

Error! Use the Home tab to apply 0 to the text that you want to appear here. Appendix B.4: Average Height of Green Onions in Set 2.

Day	Mix LEDs				Red LEDs				Blue LEDs				Control (Sun)			
	#1	#2	#3	Ave.	#1	#2	#3	Ave.	#1	#2	#3	Ave.	#1	#2	#3	Ave.
1	0.00	0.50	0.00	0.50	0.40	0.00	0.00	0.40	0.00	0.40	0.00	0.40	0.00	0.00	0.20	0.20
2	0.50	1.20	0.30	0.67	0.80	0.50	0.00	0.65	0.00	1.00	0.20	0.60	0.00	0.30	0.40	0.35
3	0.77	2.02	0.50	1.10	0.83	0.80	0.00	0.82	0.00	1.00	0.40	0.70	0.00	0.60	0.50	0.55
4	1.17	3.30	0.60	1.69	1.17	1.28	0.00	1.22	0.30	1.20	0.80	0.77	0.00	0.67	0.60	0.63
5	1.930	4.71	0.63	2.43	1.32	1.36	0.00	1.34	0.40	1.30	1.00	0.90	0.00	0.70	0.70	0.70
6	2.00	5.53	1.08	2.87	1.06	1.34	0.00	1.47	0.60	1.82	1.30	1.24	0.00	0.78	0.70	0.74
7	2.10	6.35	1.30	3.25	1.95	1.73	0.00	1.84	1.00	2.20	1.25	1.48	0.00	1.00	0.80	0.90
8	2.47	7.24	1.78	3.83	2.31	2.00	0.00	2.16	1.10	2.51	1.74	1.79	0.00	1.16	1.10	1.13
9	2.72	8.53	1.83	4.36	2.75	2.28	0.00	2.51	1.40	3.29	2.68	2.46	0.00	1.35	1.06	1.21
10	3.10	9.86	2.19	5.05	2.98	2.67	0.00	2.82	1.83	4.31	3.20	3.12	0.00	1.50	1.42	1.46
11	3.25	10.42	2.43	5.36	3.20	2.91	0.00	3.05	1.92	4.89	3.81	3.54	0.00	1.57	1.66	1.61
12	3.53	10.97	2.59	5.69	3.53	3.24	0.00	3.38	2.28	5.03	4.34	3.88	0.00	1.83	1.85	1.84
13	3.96	11.53	2.93	6.14	3.83	3.33	0.00	3.58	2.88	5.64	5.16	4.56	0.00	2.20	2.08	2.14

*Ave. = Average value

Appendix C.1: Average Fresh Weight and Dry Weight of Green Onions for Set 1.

Condition		Fresh weight (g)			Dry weight (g)		
			Average	S.D.		Average	S.D.
Mix LEDs	#1	13.57	10.88	3.79	5.10	3.53	2.22
	#2	1.00			0.30		
	#3	8.20			1.97		
Red LEDs	#1	1.10	7.78	0.40	0.00	2.05	0.64
	#2	8.07			2.50		
	#3	7.50			1.60		
Blue LEDs	#1	11.60	10.03	0.42	3.50	3.93	1.13
	#2	11.00			6.60		
	#3	7.50			1.70		
Control (Sun)	#1	4.80	4.69	0.09	1.50	1.70	0.28
	#2	4.57			1.60		
	#3	4.70			2.00		

*S.D. = Standard Deviation

Appendix C.2: Average Fresh Weight and Dry Weight of Green Onions for Set 2.

Condition		Fresh weight (g)			Dry weight (g)		
			Average	S.D.		Average	S.D.
Mix LEDs	#1	1.30	2.30	0.14	0.10	0.17	0.07
	#2	4.50			0.40		
	#3	1.10			0.00		
Red LEDs	#1	1.40	1.55	0.21	0.00	0.10	0.14
	#2	1.70			0.20		
	#3	0.00			0.00		
Blue LEDs	#1	0.80	2.07	0.57	0.00	0.23	0.07
	#2	2.30			0.30		
	#3	3.10			0.40		
Control (Sun)	#1	0.00	0.35	0.07	0.00	0.00	0.00
	#2	0.30			0.00		
	#3	0.40			0.00		

*S.D. = Standard Deviation