Effects of different colors of LED light as an artificial light source on the Growth of *Abelmoschus esculentus* var Smooth Green seedlings

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Abstract

Artificial lighting, including high-pressure sodium lamps, fluorescent lamps, and light-emitting diodes (LEDs), has been used to aid in the growth of many plants. However, there is still limited knowledge as to the effects of red, blue, and green LED lights on the growth of *Abelmoschus esculentus* var. smooth green. Thus, the effects of LEDs as an artificial light source on the plant height and root length of *Abelmoschus esculentus* var. smooth green have been examined in this study. Seedlings that were germinated for 14 days were tested in four separate setups: three treatments and one control. Results showed that at the end of the 14-day LED light treatment from 6:00 AM to 6:00 PM, the plant mortality percentage was 100% in all treatment groups. As a result of the limited amount of data gathered, the researchers were unable to conduct data analysis.

Introduction. - For many years, light sources have been deeply studied in the biological and horticultural sciences. Along with the large number of genes affected by the light under which plants are grown [1], photosynthetic phenomena heavily rely on these light sources. However, as there are regions wherein sunlight, the natural light source, is insufficient for optimal growth, total plant growth and yield have been affected [1,2]. In order to resolve these issues, artificial light sources such as high-pressure sodium lamps, fluorescent lamps, and light-emitting diodes (LEDs) have been developed and studied.

While a number of artificial light sources have been developed, research by Hamamoto and Yamazaki (2009)[3], Lu *et al.* (2012)[4], Darko *et al.* (2014)[5], and Degni *et al.* (2019)[6] claimed that LEDs provide more benefits compared to the other artificial light sources due to their high energy efficiency, long lifetime, cool emitting surface, low power consumption, and high photosynthetic active radiation (PAR). A portion of the light spectrum called high photosynthetic active radiation (PAR), which has wavelengths between 400 and 700 nm, is used by plants to undertake photosynthesis. The control over spectral composition and light intensity to match plant photoreceptors also allows the improvement and increase in growth, morphology, and other physiological processes of various plant species, including lettuce, potato, pepper, radish, green vegetables, and some other plants [1]. Moreover, according to Darko *et al.* [5], LED technology has been predicted to replace fluorescent and high-intensity discharge (HID) lamps in horticultural systems and to modify controlled growth environments for plants. These benefits brought about by LED artificial light sources led to the development of numerous research as to its effects on various plant species, as mentioned above.

LEDs as artificial light sources have been studied for over two decades. In a study by Bula *et al.* [7], lettuce (*Lactuca sativa* L. 'Grand Rapids') plants were maintained under the LED irradiation system at a total PPF of 325 $\mu mol{\cdot}s^{-1} \cdot m^{-2}$ for 21 days in order to test the effects of using LED as a radiation source for plants and compare them to that of the cool-white fluorescent lamps, which were more widely used at that time. The changes in plant growth responses, phase transitions, and pigment accumulation of *Brassica juncea* (vegetable mustard), *Lactuca sativa* (lettuce), *Ocimum gratissimum* (clove basil), *Coleus blumei*, and *Tagetes patula* (French marigold) have also been observed in different light environments composed of red and blue LED lights with the peak wavelengths of 460, 635, and 660 nm [8]. Moreover, *Lycopersicum esculentum* L. cv. MomotaroNatsumi (tomatoes) , *Brassica oleracea* L. cv Winterborn (kale plants), *Allium cepa* L. (onions), *Spinacia oleracea* (spinaches), *Capsicum annuum* L. (sweet peppers) , *Brassica campestris* L. (Chinese cabbages) and *Cucumis sativus* L. (cucumbers) have also been studied in red, blue and green LED sources of various combinations and wavelengths as the changes in their physiology such as the reduction of nitrate content, higher chlorophyll content and promoted petiole elongation, increased in leaf area, fresh and dry weight and more were recorded and analyzed [9-14,4]. Different LEDs have different colors, but green, red, and blue are commonly studied. Furthermore, LED lights designated at 3 and 5 watts are commonly used in simulated growing environments for crops these days [15]. The previous research [4,5,1] has established knowledge about the effects of these lights on numerous species of plants—ranging from fruits, vegetables, and even

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flowers—and has proved that each kind of light may have varying effects on the characteristics of the species and that there is no universal formula for it.

Crop failures, natural disasters, insect pests, and diseases, as well as out-of-season supplies, have all contributed to a reduction in vegetable production as these are some of the major constraints to *Abelmoschus esculentus* quality and quantity [16,17]. Despite the knowledge on the effects of LED as an artificial light source to various plants such as strawberry [18], lettuce [19], tomato [4], there is still limited knowledge as to the effects of red, blue, and green LED lights on *Abelmoschus esculentus*, or more commonly known as okra, of the smooth green variety. According to Degni *et al.* [6] and Roy *et al.* [20], okra is a mineral-rich vegetable with anti-diabetic and therapeutic characteristics that is widely cultivated around the world in tropical, subtropical and warm temperature regions. Furthermore, it can tolerate a wide range of soil types, which is especially beneficial for countries with varying geological characteristics such as the Philippines. Okra seeds, which are a source of oil and protein, and okra pods, which are a significant source of dietary fiber, also offer diverse medical benefits [20]. Furthermore, as the plant maturity of okra only takes around 60-180 days after sowing, its importance is heightened in the food production industry. In addition to this, according to the Department of Agriculture, Philippine okra production will soon reach the Korean market as the Philippines begins exporting them for the 2021-2022 season after meeting both countries' agreed-upon conditions. Fresh okra had also already been exported to Japan prior to Korea exportation, which further proves its high economic potential as one of the countries' main exports.

In a study by Degni *et al*. [6], each light treatment was modified to provide a specified amount of light intensity to the okra samples, ranging from 455 nm to 635 nm. There are some existing research; however, the parameters that have been measured focus on germination rate and time [6] and reproductive responses such as position and number of flowers [3]. Thus, this study aims to determine the effects of using red, blue, and green LED lights as an artificial light source on the root length and plant height of *Abelmoschus esculentus* var. smooth green. Based on the findings of previous research [5,1,6], the researchers have come to hypothesize that the use of LED as an artificial light source shall increase the plant height and root height of the *Abelmoschus esculentus* var. Smooth green plants are grown under it. This study would aid in developing better *Abelmoschus esculentus* cultivation methods using artificial light sources in order to supply the required demand in different countries such as Brazil, India, Thailand, and the Philippines, where *Abelmoschus esculentus* is popular and also widely cultivated [21]. It could also aid in actualizing the economic potential of *Abelmoschus esculentus* as one of the Philippines' major exports especially to countries such as Korea and Japan. Moreover, local horticulturists may also be guided by this study into developing LED light treatment setups so that a better quality of okra plants may be produced.

This study aimed to measure the plant growth of the *Abelmoschus esculentus* var. smooth green (okra) plants under red, blue and green light-emitting diodes (LED) as the light source. It specifically aimed to:

(i) To measure the plant heights of the *Abelmoschus esculentus* var. smooth green plants in four different setups (plants under the white LED bulb are in one control group, while plants under green, blue, and red LED bulbs are considered as treatment group) after 14 days,

(ii) To measure the root lengths of the *Abelmoschus esculentus* var. smooth green plants in four different setups (plants under the white LED bulb are in one control group, while plants under green, blue, and red LED bulbs are considered as treatment group) after 14 days; and

(iii) To compare the plant height and root length of the *Abelmoschus esculentus* var. smooth green plants in four different setups (plants under the white LED bulb are in one control group, while plants under green, blue, and red LED bulbs are considered as treatment group).

Methods. - A total of 200 seeds were sowed throughout the 14-day germination period. Using random sampling, 60 samples were chosen from the total number of plants germinated. Three trials were conducted, each with fifteen repetitions of one control group and three treatment groups (blue, red, and green). Three set-ups were simultaneously conducted in Barangay Sto. Nino Sur, Arevalo, Iloilo City, Iloilo , Barangay Barangay Sohoton, Barotac Nuevo, Iloilo and Barangay Union, Nabas, Aklan using the same soil series. The samples were then monitored and watered regularly. For 14 days, the plants were under the control and treatment groups. After that, measurements of plant height and root length should be obtained. However, because the data was insufficient, no data analysis was performed.

Germination of Seeds. The *Abelmoschus esculentus* var. smooth green (okra) seeds from East-West Seed were used in this experiment. Each seed was sown in each of the cells of the two 100-cell germination trays, for a total of 200 seeds subject to germination. Then, the germination trays were placed in an area with little to no shade, such that the seeds could receive as much and as even light as possible. The seeds were monitored for 14 days and were watered with 25 mL daily.

Experimental Setup. Each member prepared a closed room to accommodate one trial of each treatment group and one trial of the control group. Then, four wooden tables of dimensions 0.5m x 1.0m x 1.5m were prepared, with a black cloth wrapped around the four posts on the edge. There was also a wooden bar running across the table along its horizontal, where a 5W LED light bulb that has a 25 cm vertical distance from the top of the pots, was hung from [4]. All of the bulbs were acquired from the same store. After the initial germination period of 14 days, the fishbowl randomization method was used to randomize the choosing of seedling samples to be transplanted. All setups used garden soil to fill each pot with a diameter of 9 cm and a height of 8 cm, where each seedling was transferred to. To avoid biases on the possible outcome of the experiment, the lottery or fishbowl randomization method was used in dividing the samples into control and treatment groups. There was a total of 1 control group and 3 treatment groups.

Measurements and Parameters. The parameters were measured after 14 days. The plant height was measured from the base of the root to the longest leaf tip using a vernier caliper in millimeters adapted from Preetha & Stanley [22]. For the root length, the seedlings were carefully lifted out of the tray to avoid damaging the roots. It was measured from the base to the end of the longest root using a vernier caliper in millimeters adapted from Shahid *et al.* [23].

Data Analysis. In testing the significance of the germination and seedling emergence parameters, the One-Way Analysis of Variance (One-Way ANOVA) and Fisher's Least Significant Difference (LSD) method shall be used to create confidence intervals between factor level means, with a level of significance of 0.05. In case of plant mortality during the experiment, the Tukey's Range test may also be used for the differences between the treatment means. Lastly, the software to be used for the above-mentioned procedures shall be Microsoft Excel (2016 Version).

Safety Procedure. Safety precautions were observed while conducting the study. Disorganized electrical wirings may cause electrocution, thus proper installment and monitoring of electrical materials were observed. High-energy blue light from the LED bulbs may also cause damage to the eyes, thus the researchers wore protective glasses and limited their exposure to the light. During the transplanting of seedlings, pathogenic bacteria in soil may cause infections, thus wearing protective gloves was observed. Lastly, each sharp edge of the experimental table was covered with foam to minimize potential risk for the researchers.

Results and Discussion. - This study aimed to determine the effects of different colors of LED light (red, blue and green) as an artificial light source on the plant growth of *Abelmoschus esculentus* var. smooth green seedlings. The root lengths and plant heights under the three treatment groups and one control group were collected after 14 days. However, after the collection of data, the researchers were not able to perform the data analysis procedures as the number of surviving sample populations was insufficient due to the 100% mortality rate in all plants under the treatment groups.

For each of the three trials of the three treatment groups, none of the 15 plants have survived. Thus, the mortality percentage of the *Abelmoschus esculentus* under the red, blue, and green LED light is 100%. Under the control treatment, there is only a mortality percentage of 53.33% as there had only been a total of 24 *Abelmoschus esculentus* from the three control setups that have survived. Due to the limited number of surviving sample populations from the control group, the data has been insufficient, and thus researchers have been unable to conduct the data analysis methods. The measurements of plant heights and root lengths recorded on plants grown in the control set-up are shown in the tables below (Tables 1-3).

Table 1. This table shows the measurements of plant height and root length recorded by Member 1 (Arsenal) on the plants grown in the control setup.

Member 1	
Plant Height (mm)	Root Length (mm)
166	38
164	24
157	11

Table 2. This table shows the measurements of plant height and root length recorded by Member 2 (Belicena) on the plants grown in the control setup.

Member 2	
Plant Height (mm)	Root Length (mm)
156	41
131	17
155	60
140	54
166	61
167	34
178	65
43	86
132	46
20	94

Table 3. This table shows the measurements of plant height and root length recorded by Member 3 (Gubaton) on the plants grown in the control setup.

Member 3	
Plant Height (mm)	Root Length (mm)
150	80
156	63
155	100
157	37
162	246
143	45
120	45
140	187
162	147
144	96
131	52

Limitations. As shown in figure 1, in all setups, the mortality of *Abelmoschus esculentus* plants in the treatment groups rises over time. The researchers have identified five possible factors which have affected the growth and eventual mortality of the *Abelmoschus esculentus* plants: light intensity, distance between the plant and LED bulb, daily weather conditions and temperature, amount of water, and lastly limitations in equipment. First, it is possible that the light intensity of the LED bulbs has been insufficient to support the growth of all 15 *Abelmoschus esculentus* plants in one setup. In a study by Liu *et al.* [24], 24 units of 3W LED bulbs had been used in one of the setups while on the other hand, in a study conducted by Sabzalian *et al.* [25], 1.0 W LED bulbs had been used. Each setup had been placed in each of the four growth cabinets, and each cabinet supported 120 of these 1.0W LED Lights. In another study by Lu et. al. [4], each unit of the LED bulb used had the wattage 18W. According to the above studies by Liu *et al.* [24], Lu *et al.* [4], and Sabzalian *et al.* [25], LED bulbs with different wattages were utilized in a set-up; however, according to a study conducted by Abeena *et al.* [15], 3 watts and 5 watts of LED light have also been commonly used in growing indoor plants or under simulated environments. Thus, this study utilized a 5-watt LED bulb per set-up. Since the distance between the bulb and the top of the pot had been adapted from the study by Lu et. al [4], it could be that the light intensity received by each plant had been insufficient as the higher wattage of the LED bulb, the higher the light intensity it produces. On the other hand, it is also possible that the distance between the light bulb and the plant had a major effect on the growth of the plant. As mentioned above, the distance between the bulb and the top of the pot of 25 cm had been adapted from the study by Lu et. al [4]. However, as the plant grows, its height also increases – which means that the plant had been constantly growing closer to the LED bulb, and that the closing distance might have caused the *Abelmoschus esculentus* samples to receive too much heat from the bulb then start to wither at around Days 4 to 8.

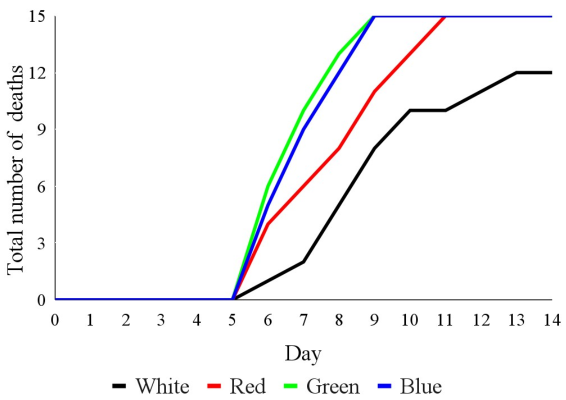

Figure 1(a). This graph shows the number of cumulative plant mortalities as recorded daily of Member 1 (Arsenal).

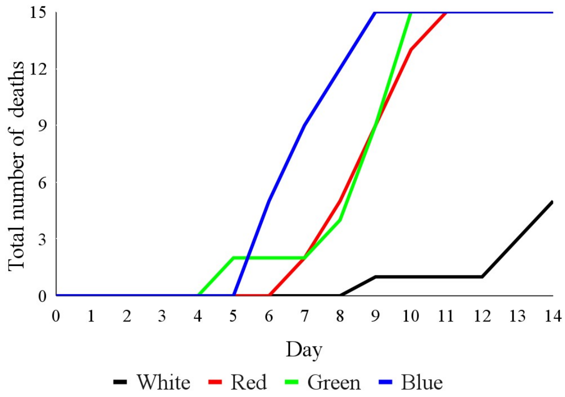

Figure 1(b). This graph shows the number of cumulative plant mortalities as recorded daily of Member 2 (Belicena).

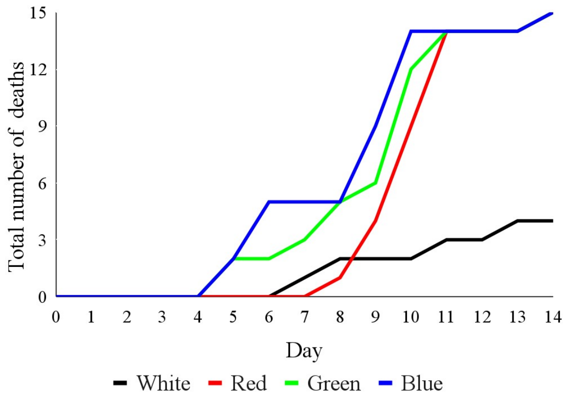

Figure 1(c). This graph shows the number of cumulative plant mortalities as recorded daily of Member 3 (Gubaton).

This is evidenced by the graphs above which shows the growth trend of the *Abelmoschus esculentus* in all setups. It could be observed that the mortalities had only started from around Day 4 to Day 8, and that by Day 14, all *Abelmoschus esculentus* under the treatment setups had already died. According to a study by Wang and Folta (2013), far-red light, which is the dominant wavelength, is what causes the most noticeable changes. Additionally, there are differences in the ways that the green, red, and blue wavebands affect the plant's growth and development. The wavelengths that most strongly stimulate photosynthesis are at the red end of the spectrum (600–700 nm), followed by the blue region (400–500 nm), and finally the green region (500-600 nm). As can be observed from the graphs, plants in the treatment setup with green LED died earlier than those in the setup with red and blue LED. Plants with withered leaves have been constantly monitored since the moment the stem breaks or falls, the plant is deemed to be dead. The dead plant's condition supports it as it wilts in the days that follow after it was declared dead until the 14-day period. The pale leaves and withering of the plants, which have been noticeable on the plants from the treatment groups, are indicators of overwatering and/or overexposure to light.

In the study by Liu *et al.* [24], the growth temperature had been set to 25±2 °C, which is similar to the outside average daily temperature. However, in another study by Degni *et al.* [6], the temperature had only been recorded daily but not controlled. Due to the difference in the researchers' setup locations, there might have been variations in the daily weather conditions which may have affected the growth of the *Abelmoschus esculentus* during the germination phase of the study.

Another factor that had also been considered is the amount of water that had been used for the plants. As adapted from the study by Lamont 1999[26], each plant has been watered with 25mL of water daily. However, after observing the soil by the end of 14 days, most of the pots with dead plants had wet to moist soil. Since *Abelmoschus esculentus* is a heat-loving crop, it is possible that the amount of water had been more than what is needed in the setup. Thus, the mortality of the plants might have also been affected.

Moreover, in studies conducted by Liu et al. [24] and Degni et al. [6], each light treatment has been adjusted to give a specific amount of light intensity of around 455 nm to 635 nm. The study included five treatment groups: blue, green, red, blue and green, and red and green. However, due to the limitations in the availability of equipment, the researchers have been unable to measure the light intensity received by the plants. This may have affected their growth, and have thus been one of the factors that led to such results.

Conclusion. - Based on the obtained results, it may be concluded that LED light as an artificial light source for *Abelmoschus esculentus* var. smooth green resulted in a 100% mortality percentage on all the treatment setups in this study.

Recommendations. - It is recommended to either use an LED light bulb with a higher wattage or use multiple light bulbs in each setup to increase the light intensity received by the plants. LED strips may also be used in place of LED bulbs as the light produced by the source is dispersed more evenly and consistently among the plants. Furthermore, it is recommended to measure and to determine the specifications of the LED bulbs to be used, such as light intensity, spectrum, and the area covered by the light, since these are some of the factors that may determine the output of the LED light sources. It is also recommended to test the effects of mixed colors and wavelengths, as different plants require specific conditions to obtain optimum growth. Aside from the LED parameters that may have influenced okra growth, other aspects to be considered are temperature and humidity of the setup environment, and the amount of water received by the plants could also be reduced. It is also recommended that a control set-up be in place under normal conditions.

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