Plant growth chamber with integrated air conditioning system, periodic irrigation, and adjustable photosynthetic light wavelength

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Abstract. The increase in the average temperature due to climate change affects the crop yield production and it can lead to food insecurity. Rapid breeding helps increase crop yield production and improve the overall crop quality. The researchers designed a plant growth chamber with integrated air conditioning system, periodic irrigation, and adjustable photosynthetic light wavelength. The growth rate of the representative plant, green span lettuce, grown in the plant growth chamber is compared to conventional planting. Factors such as growth period rate, dry weight, and overall produce quality are considered. It was found that implementing a 24-hour photoperiod, drip irrigating 50 mL per plant every 2 days, adding vermicast to the cocopeat at a ratio of 1:1 and maintaining a temperature range of 20 to 25 degrees Celsius produced a higher relative growth rate. In consideration of additive nutrients, the addition of vermicast added a substantial increase in the relative growth rate. Quality was also improved due to the correlation of the relative growth rate and plant quality.

1. Introduction
Lettuce is considered a cool weather vegetable that should be planted during late summer in the Philippines [1]. The study of [2] also found that fancy lettuce varieties had an increased demand due to fast-food chains that influenced the eating habits of the Filipino people, but these fancy lettuce varieties require modern greenhouse technologies for production which requires a large capital that cannot be supported by all farmers. To induce speed breeding, a Plant Growth Chamber is required which is a fully enclosed environment capable of controlling the environmental parameters such as temperature, humidity, CO2 composition, light intensity, and light wavelength [3]. Numerous studies found that better quality crops may be grown faster by providing purple light as photosynthetic light. However, the light wavelength may vary as different crops have different responses to different wavelengths. The combination of red and blue light or purple stands as an effective light source for a plant’s growth because it provides increased chlorophyll content, increased biomass and phytochemical content, and overall enhanced nutritional value [4][5][6]. Purple light using red and blue LED light arrays allows lettuce production in conditions where sunlight is unavailable and that purple LED lighting improved lettuce crop breeding speed by increasing the height and root ratio of lettuce faster than regular sunlight exposure [7]. Aside from the lighting, a
periodic irrigation system is necessary to provide daily water requirements for the plants and soil moisture. It is observed to have yield increase, easier harvesting, reduced water consumption and better-quality lettuce when lettuce is drip irrigated [8].

This study primarily focused on the design and fabrication of a plant growth chamber for the speed breeding with romaine lettuce (Lactuca sativa L. var. longifolia) as the representative plant. Several parameters were considered to enhance the growth and quality of the plant. The proposed design of the plant growth chamber controlled and maintained the environmental parameters such as indoor temperature, humidity level and light wavelength. In addition to this, a periodic irrigation system is installed to maintain the amount of water used and less human intervention. Thus, this research designed and fabricated a plant growth chamber with integrated air conditioning system, periodic irrigation, and adjustable photosynthetic light wavelength. Also, the seed germination rate and quality of the representative plant, romaine lettuce must be increased and enhanced. The study highlights design and testing of a plant growth chamber with integration of air conditioning system and adjustable photosynthetic light wavelength. It also focuses on the drip irrigation system.

2. Materials and Methods

To implement the plant growth chamber concept as shown in Figure 1, a closed space was designed with vapor compression air-conditioning system with 2 HP unit, drip irrigation system, smart LED lighting system and a built-in temperature and humidity meter. To carry out the testing procedures, a seedling tray was used and planted with lettuce seeds and allowed to sprout in the plant growth chamber environment with a purple led light exposure at 100% intensity and a 24-hour cycle. To further explain the environmental parameters, the ideal relative humidity inside a controlled-environment chamber is in the range of 60 to 70% [9]. The growth rate of lettuce is stable at a temperature range of 20-25°C [10] and purple light is the best option as lighting for plant growth chambers [4]. In addition, an inlet and exhaust fan were installed that ran for 5 minutes every 3 hours to maintain the natural CO2 level of the environment. These parameters were repeated for other trials, but the lighting system and irrigation system were varied throughout the testing cycles.
chamber’s enclosure. On the other hand, the water flow for the periodic irrigation was monitored using a flow meter. The green span lettuce sprout planted in a Styrofoam cup was placed inside the plant growth chamber and the researchers observed its growth until harvesting stage. The researchers documented its growth through pictures and compared it with the germination rate of green span lettuce at Zacky’s farm. The place has an ambient temperature ranging from 21-26°C with relative humidity of around 84%.

The researchers conducted two simultaneous testing for the prototype testing of the plant growth chamber. Simultaneous testing means that green span lettuce grown with and without fertilizer or nutrients are placed inside the plant growth chamber at the same time. The ratio of vermicast to cocopeat is 1:1 while the ratio of nutrients from the vermicast shows 12:1 carbon to nitrogen ratio. A second trial was done with the same arrangement where half of the lettuce sprouts are grown with fertilizer or nutrients. The fertilizer used is vermicast which is an organic fertilizer made from castings of worms. The plant quality and relative growth rate for both tests were compared and analyzed. The researchers used the formula by [11] for determining the relative growth rate of plants between two-time intervals. Relative Growth Rate (RGR) is a well-known indicator of plant strategy with respect to crop yield as identified with environmental stress and disturbance regimes. In specific to testing of the growth of green span lettuce, two trials of simultaneous testing were done. The objective of the simultaneous testing was to investigate if there are any advantages or disadvantages of growing plants in the plant growth chamber with and without nutrient or fertilizer supplement. At different time intervals, the researchers weighed the lettuce plant including its roots to determine its dry weight.

To calculate the Relative Growth Rate of lettuce between two-time intervals, the researchers used the equation of Relative Growth Rate by [11] described by equation (1)

\[
RGR = \frac{(\ln W_2 - \ln W_1)}{t_2 - t_1}
\]

(1)

Where, 
\( RGR = \) relative growth rate
\( W_1 = \) Initial dry weight of plant at time \( t_1 \), grams
\( W_2 = \) Final dry weight of plant at time \( t_2 \), grams
\( t_1 \) and \( t_2 \) = time, days

3. Results and Discussion

For the initial testing of the plant growth chamber, the parameters such as temperature, relative humidity, light intensity, and light duration were observed. The initial tests were done to guarantee that the plant growth chamber will work within the required parameters for the green span lettuce. The temperature inside the enclosure is within 20°C to 25°C and the humidity is kept at a range of 60% to 70%. With continuous observation, it is determined that the plant growth chamber can work within these parameters. The researchers tried different light intensity levels and light duration to observe its effect to the growth of green span lettuce. The seedlings showed considerably slow growth for the first 3 trials (seedlings without nutrients used). The seedlings grown in conventional farming will start to show its one true leaf within 7 days but the seedlings in the plant growth chamber took 9 days.

There were two trials done for green span lettuce seedlings with nutrients. The temperature and humidity range are kept at the same range with the first 3 trials done on seedlings without nutrients. A 24-hour photoperiod increases the biomass of the lettuce [12]. The ratio of the soil and nutrients were also varied for these trials. The researchers first tried the recommended 1:1 ratio by mass of soil and nutrients, and for trial 2 a ratio of 3:1 was tested. The green span lettuce seedlings showed a favorable result with the settings of the trial with 100% light intensity (24-hour photoperiod) and a ratio of 1:1 for the soil and vermicast. Therefore, it was decided to operate the plant growth chamber at these set parameters. The drip irrigation system is not utilized for the initial testing because the seedlings need to be watered using a mist applicator. In addition, the seedlings are sensitive to extra soil moisture that slows the seedling’s growth rate.

A simultaneous testing was done for green span lettuce with and without nutrients. There were six test data taken at different time intervals as shown in Table 1. For this testing, the plant growth chamber is operating at a temperature within 20°C to 25°C, a relative humidity range of 60% to 70%, and a 100% light
intensity with 24-hour photoperiod. The periodic irrigation system consists of an automatic watering pump and drip irrigation tubing. The drip irrigation system supplies each lettuce sprout 50 mL every 2 days so that it gives moisture content to the soil [13]. The interval of the days for weighing the lettuce are in parallel with the test data taken from the beneficiary which is Zacky’s farm. As shown on Table 2, Relative Growth Rate (RGR) for the first trial, the RGR for the lettuce grown with nutrients is the highest with an average relative growth rate of 0.0657. It was followed by the lettuce grown without nutrients and the lowest average relative growth rate value is for the test data taken from the farm.

Table 1 Results of Green Span Lettuce for Trial 1

| Farm | Lettuce w/ Nutrients | Lettuce w/o Nutrients | Farm |
|------|---------------------|----------------------|------|
|      | Dry weight (g)      | Growth Period        | Dry weight (g) | Growth Period |
| 1    | 9                   | 7                    | 9               | 7            |
| 2    | 30                  | 14                   | 28              | 14           |
| 3    | 97                  | 26                   | 95              | 26           |
| 4    | 129                 | 39                   | 124             | 39           |
| 5    | 154                 | 45                   | 143             | 45           |
| 6    | 166                 | 55                   | 163             | 55           |

Table 2 Relative Growth Rate (RGR) for Trial 1

| Farm | Lettuce w/ Nutrients | Lettuce w/o Nutrients | Farm |
|------|---------------------|----------------------|------|
|      | Dry weight (g)      | Growth Period        | Dry weight (g) | Growth Period |
| 1 & 2| 0.1720              | 0.1621               | 0.1132 |
| 2 & 3| 0.0978              | 0.1018               | 0.1669 |
| 3 & 4| 0.0219              | 0.0205               | 0.0138 |
| 4 & 5| 0.0295              | 0.0238               | 0.0135 |
| 5 & 6| 0.0075              | 0.0131               | 0.0124 |
| Average RGR | 0.0657 | 0.0643 | 0.0640 |

From Figure 2, it is noticeable that the relative growth rate values are close to each other. The decline in the three curves shown is also expected throughout the growth of the green span lettuce. As stated from the study of [14], a plant’s growth is exponential, but it becomes linear once the critical mass is reached. A high relative growth rate value is also associated with high net assimilation rate (NAR) and high specific leaf area (SLA) as these two are general growth components of RGR [15]. The same procedure is done for the second trial of the plant growth chamber. It showed a similar result where the lettuce with nutrients has the
highest average relative growth rate while the lettuce grown in the farm is the lowest as shown in Table 3, Table 4, and Figure 3. The actual photos of the lettuce grown in these conditions can be seen in Figure 4.

Table 3. Results of Green Span Lettuce for Trial 2

| Farm | Lettuce w/ Nutrients | Lettuce w/out Nutrients | Farm |
|------|----------------------|-------------------------|------|
|      | Dry weight (g) | Growth Period | Dry weight (g) | Growth Period | Dry weight (g) | Growth Period |
| 1    | 9          | 7              | 9              | 7              | 13             | 7              |
| 2    | 32         | 14             | 30             | 14             | 37             | 16             |
| 3    | 98         | 26             | 94             | 26             | 98             | 22             |
| 4    | 132        | 39             | 127            | 39             | 133            | 43             |
| 5    | 157        | 45             | 145            | 45             | 155            | 55             |
| 6    | 168        | 55             | 164            | 55             | 170            | 62             |

Table 4. Relative Growth Rate (RGR) for Trial 2

| Farm | Lettuce w/ Nutrients | Lettuce w/out Nutrients | Farm |
|------|----------------------|-------------------------|------|
| 1 & 2 | 0.1812            | 0.1720                | 0.1162 |
| 2 & 3 | 0.0933            | 0.0952                | 0.1623 |
| 3 & 4 | 0.0229            | 0.0231                | 0.0145 |
| 4 & 5 | 0.0289            | 0.0221                | 0.0128 |
| 5 & 6 | 0.0068            | 0.0123                | 0.0132 |
| Average RGR | 0.0666 | 0.0649 | 0.0638 |

Figure 3. Relative Growth Rate for Trial 2
4. Conclusion

The plant growth chamber was designed and fabricated using materials such as aluminum sheets, aluminum frames, square aluminum tubes, and polyethylene foam insulation to compensate for the internal heat gain and indoor-outdoor temperature differences. In testing of the plant growth chamber, considerable green span lettuce growth environments were exhibited, the chamber has shown that it can grow at a temperature range of 20 to 25 degrees Celsius, at a 24-hour photoperiod and through drip irrigation system.

In measuring the growth rate, the use of the relative growth rate (RGR) analysis has shown efficacy in determining the growth rate of the lettuce plant from sprout to harvest. In the trials done, the relative growth rate was augmented through implementing drip irrigating 50 mL per plant every 2 days and addition of vermicast to the cocopeat at a ratio of 1:1 The relative growth rate was successfully augmented with these conditions. In the use of additive nutrients, the addition of vermicast added a valuable increase to the relative growth rate in comparison to planting. In terms of quality, quality was improved due to the correlation of the relative growth rate to overall plant quality.

The use of a plant growth chamber is not limited to a specific type of plant. The researchers used lettuce as the representative plant since it is sensitive to temperature and other environmental conditions. Future researchers may use other plants that require a different operational range. It is preferable to test plants that are also sensitive to changes in temperature and can only be planted on specific areas. The use of the plant growth chamber is advantageous for trying out other crops since the temperature inside the enclosure can be varied. The light intensity and light duration as well as the drip irrigation system can also be changed depending on the plant.

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