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Smart Lighting Operation for The Growth of Bird's Eye Chili Plants Using Arduino Uno

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Unfavorable weather conditions, climate change, and pests can disturb chili cultivation. The "Smart Lighting Operation for the Growth of Chili Plants (Capsicum Frutescens L) Based on Arduino Uno" is designed to help farmers who lose land or experience crop failure due to unpredictable weather, which prevents plants from receiving optimal sunlight. Here, the researcher utilizes Arduino Uno in the control system to process data and determine the values obtained from the system. The light sensor (BH1750) detects light radiation (lux), and the temperature sensor (DS18B20) detects temperature (°C). White daylight LEDs are used for lighting. Testing is conducted using the static group comparison method to compare different groups or conditions of each treatment. This research involves creating a prototype of an artificial lighting device based on Arduino Uno, which can display data and control the necessary temperature and lighting. The device is tested thoroughly according to the programmed plan to determine the significance of its impact on the development and growth of chili plants. The results show that the greatest stem height increase occurred in the third treatment, with an average of 0.6 cm per day. However, by the 15th day, the plants tended to slow down, stopping growth on the 38th day and starting to turn yellow on the 40th day. The greatest branch increase occurred in the second treatment (using the device with the door open), with an average of 2 branch nodes per day.

1. Introduction

Current agricultural sector activities tend to decline due to development focused on economic growth, resulting in the reduction of agricultural land. We all know that our country possesses the richest natural resources in the world. Before agricultural land becomes increasingly scarce, researchers will conduct experiments on the operation of artificial lighting equipment with the hope that plants can still grow indoors. One of the factors influencing plant growth is light. Sunlight significantly affects physiological processes such as photosynthesis, respiration, transpiration, stomatal opening, and closing, as well as germination and plant growth. Therefore, in this study, the lighting factor is used as a control for plant growth.

Common problems in chili cultivation include limited land, unfavorable weather conditions, climate change, and pest and disease attacks. Apart from pest and disease attacks, the impact of unfavorable weather and climate change is significant on chili cultivation [1]. In Indonesia, the average air temperature in September from 1991 to 2020 was 26.8 °C, within the normal range of 21.4 °C to 29.0 °C. However, the average air temperature in September 2022 was 27.0 °C, indicating a slight positive anomaly of 0.2 °C. Java Island is currently experiencing a temperature increase indicated by positive temperature anomalies. Rising temperatures, along with reduced water availability and climate-related natural disasters, can cause damaging effects on agricultural land. Additionally, climate change can disrupt planting and harvesting schedules and leave crops unharvested [2]. From the explanation above, the researcher aims to implement a device called the 'Prototype of Artificial Lighting Operation for Growth of Bird's Eye Chili Plants (Capsicum Frutescens L) Based on Arduino Uno,' which is intended to help farmers who have lost land due to development or experienced crop failure due to unpredictable weather, resulting in plants not receiving optimal sunlight. This control also allows chili plant owners to monitor growth continuously without expending much effort, as the device automates it. In this study, Bird's Eye Chili plants (*Capsicum frutescens L*) are used as the research object. However, it does not rule out the possibility that the tool can also be applied to other types of plants.

The artificial lighting system is a solution to overcome the issues above, as it does not require a large area, and plants can be grown at home or in buildings. Another advantage of this system is that it is controlled in such a way that environmental instability does not affect the plants within it [3].

Sunlight consists of UV rays, visible light, and infrared rays. The wavelength of visible light is 400-700 nm. Plants use visible light for photosynthesis. Chlorophyll can absorb wavelengths from red (600-700 nm) to blue (400-500 nm). The quality of sunlight is beneficial for plant growth because it has the full spectrum needed for photosynthesis. Artificial light from lamps used as a substitute for sunlight to support plant growth must be of a quality that meets these needs [4].

Currently, chili plants still depend on environmental conditions and human labor, making harvests somewhat limited and challenging. Global warming makes environmental conditions unpredictable, causing some chili plants to grow imperfectly and die. The production of bird's eye chilies is at risk during the rainy season, which can lead to pest attacks, Fusarium wilt, and yellow rot. In the dry season, weather conditions cause soil drought, slowing the growth of bird's eye chilies and leading to the emergence of pests and diseases in previously unaffected plants. Drought can also result in severe pest and disease problems for certain plants, posing a significant risk to bird's eye chili cultivation [5].

Several researchers have previously studied the use of artificial light on plants. In a study by Hernandez (2012), it was shown that adding red LEDs can increase chlorophyll content [6]. Meanwhile, Sabzalian (2019) demonstrated that adding blue LEDs can stimulate plant metabolism to improve fruit quality. However, based on the previous explanation, this research will use white LEDs with different intensities and treatments, which will then be compared to determine the best results in the artificial lighting system.

This research uses Arduino Uno in the tool's control, also known as MPPT, which is a technique that can be used to complete the process. These Maximum Power Point Tracking controller devices are utilized to configure the DC-DC Converter so that the solar panel module can harvest the maximum amount of solar energy possible [7]. With Smart Farming tools and greenhouse systems to control humidity, temperature, and irrigation based on IoT, aimed at managing the growth of lettuce using the Vertical Farming Aeroponics method to support efficient agriculture [8]. The results obtained from this research aim to determine the best outcomes for artificial lighting systems using LEDs.

2. Method

It starts with a literature study, which involves gathering relevant data and theories. The collected data and theories are discussed with the supervisor to create a research system plan. Hardware planning is conducted to determine the necessary components, followed by programming each component. Once each component is programmed, the next step is to integrate the programs for all components so that the tool can operate. The system is first tested, and if any issues arise, components are checked and reprogrammed as needed. Once the system operates normally, it is ready for use. Research is used to investigate the effect of certain treatments under controlled conditions. According to the classical concept, an experiment is a study to determine the effect of an independent variable (treatment) on a dependent variable (impact) [9].

2.1 Research Method

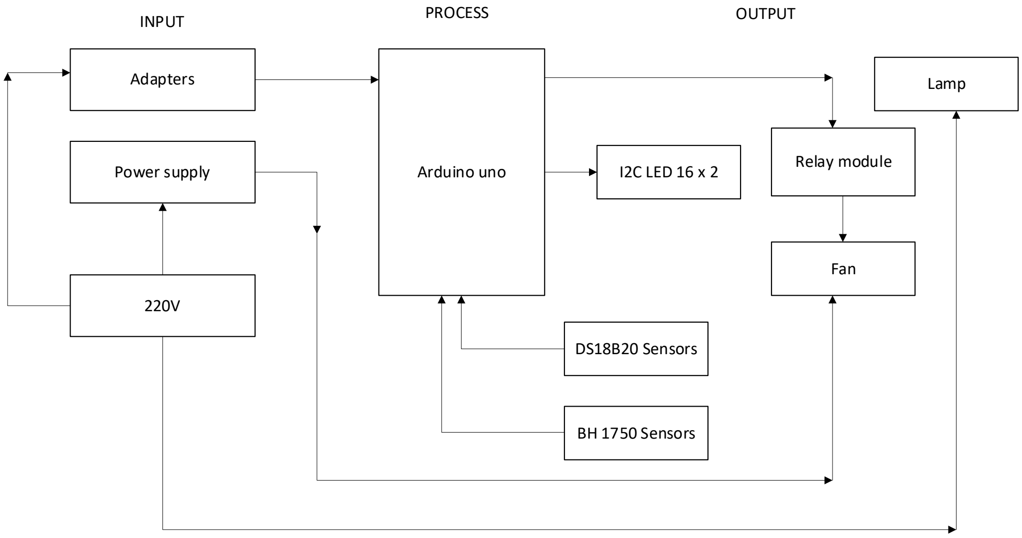


Figure 1. Block Diagram System

The block diagram, as shown in Fig. 1, explains that the Arduino Uno is used as a microcontroller, functioning as the brain of the programming. The components used as inputs are the temperature sensor (DS18B20) and the light sensor (BH1750). The outputs are a 12V DC fan and a relay as a switch. The artificial lighting used in this system consists of a 13-watt white LED. An I2C LCD is used to display temperature and light data. This device also utilizes a 220V power source and a power supply for power.

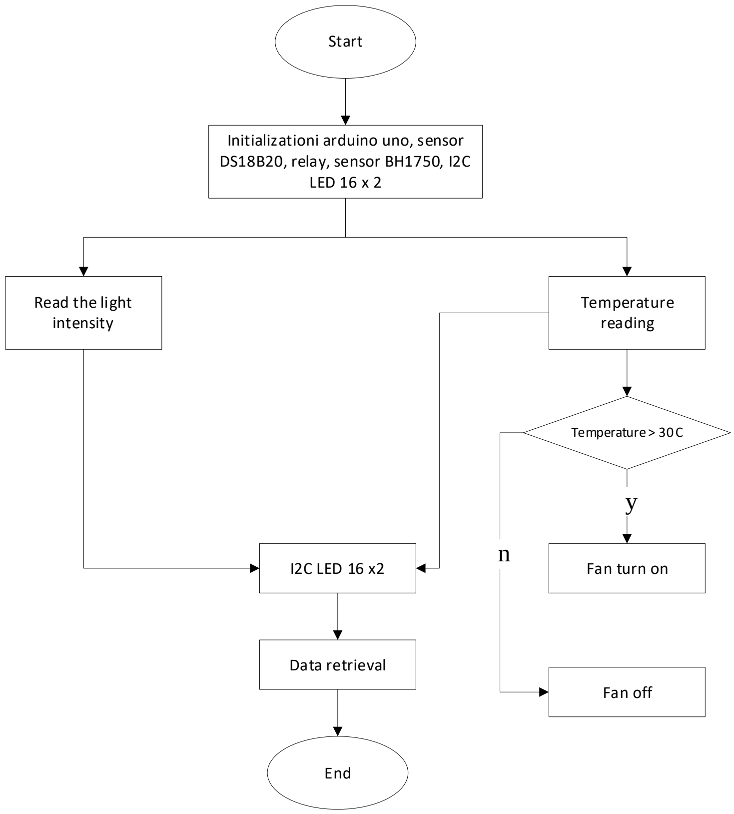


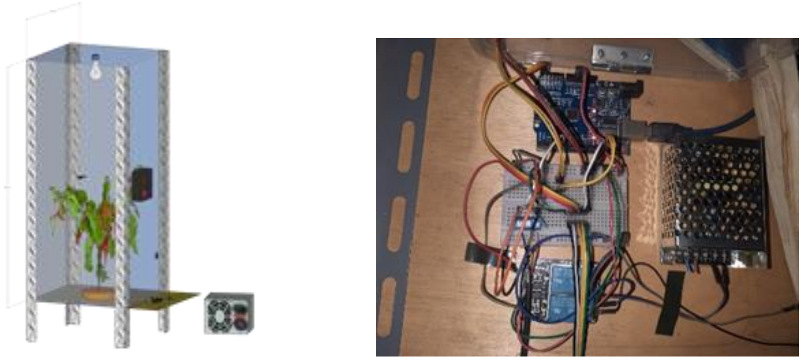
Figure 2. System Flowchart

The general overview of the working mechanism of the Arduino Uno-based Prototype for Artificial Lighting Operation for the Growth of Cayenne Pepper Plants (Capsicum Frutescens L) is as follows: when the prototype is turned on, the system will initialize the Arduino, the DS18B20 sensor, and the BH1750 sensor. Here, the power supply functions to convert the electrical energy source (e.g., AC electricity from an outlet or battery) into the appropriate voltage and current required by the devices being powered, specifically the fan as the actuator, while the Arduino Uno microcontroller is powered by a 9V 1A adapter based on the calculated load. Continuing from the previous explanation, both sensors will be active.

The DS18B20 sensor will read the temperature inside the device, and the temperature value can be viewed automatically. Thus, if the previous condition is dry or the plant needs water, the DS18B20 temperature sensor microcontroller will send a signal, which can be monitored through the LCD [10] , if the temperature exceeds 30°C, the sensor will send a signal to the Arduino to turn on the fan as the actuator. Once the temperature drops below 30°C, 'the developed system effectively removes excess hot air by extracting it through blower equipment. This process is triggered when the room temperature exceeds 30°C, ensuring a stable temperature is maintained between 24°C and 29°C' [11] The sensor will send a signal to the Arduino to turn off the fan. The BH1750 sensor will start measuring the amount of light radiation received by the plant. Both sensors will send data to the I2C, which will be displayed on the 16 x 2 I2C LED screen for research data collection. This process will continue in this manner.

2.2 System Design Method

This study uses primary data obtained from observations, experiments, and data from previous researchers as references. The variables used in the research include plant height, number of branches, room temperature, light intensity, and different treatments.



(a) (b)

Figure 3. Design: (a) Tool prototype form and (b) Form of system design

The design of this artificial lighting prototype is based on a case study from previous research. Some technological components were added, utilizing Arduino Uno as the microcontroller and several sensors such as BH1750 and DS18B20. For the first treatment, the researcher will enclose the entire device space. In contrast, for the second treatment, the researcher will open one window of the device, creating an opening that allows light to exit or enter from another source, thus resulting in different light intensity measurements within varying dimensions.

3. Result and Discussion

3.1 System test

In the sensor testing, the author uses the Mean Absolute Percentage Error (MAPE) calculation to measure how closely a forecasting or prediction model approximates the actual values, indicating the model's accuracy. MAPE is a commonly used performance evaluation metric in forecasting and prediction, particularly in the contexts of economics, finance, inventory, and other business fields.

The testing of this tool's design aims to determine whether the artificial lighting device can function and operate correctly according to the programming. The testing is conducted by connecting the USB cable linked to the Arduino to a 9V adapter with an output of 1.6A, the 12V fan to the power supply, and the LED lamp to the 220V power source. The system will then run according to the program that has been created,

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Ai-Fi}{Ai}\right| \text{x } 100\ \% \qquad (1)$$

Which n = sample size, Ai = actual data value, Fi = forecasting value.

MAPE calculations can be considered effective if the results do not exceed 10%, as predictions are deemed very accurate at this value. However, this threshold can vary depending on the context and field of application.

We did two kinds of testing in this research: light exposure and temperature testing. As a reference compared to determine the error value, we used sensors and measuring instruments for data retrieval at the same time. The test is repeated 30 times.

Table 1. Result of light exposure testing

No	BH1750 (lx)	Luxmeter (lx)	Difference	Error (%)
1	32,38	32	0,38	1,18
2	28,64	28	0,64	2,2
3	25,14	25	0,14	0,5
4	22,76	25	2,24	8,96
5	108,00	108	0	0
6	170,20	173	2,8	1,6
7	198,16	189	9,16	4,8
8	184,54	179	5,54	3,09
9	204,00	204	0	0
10	316,34	296	20,34	6,8
11	430,44	425	5,44	1,28
12	519,28	510	9,28	1,81
13	583,12	575	8,12	1,4
14	760,00	755	5	0,6
15	781,56	776	5,56	0,71
16	798,38	789	9,38	1,18
17	816,72	809	7,72	0,9
18	827,00	825	2	0,2
19	839,00	830	9	1,08
20	1100,12	1100	0,12	0,01
21	1760,58	1800	39,42	2,19
22	1760,66	1820	59,34	3,2
23	2370,42	2425	54,58	2,2
24	3340,00	3256	84	2,5
25	5520,76	5424	96,7	1,78
26	5567,14	5360	207,14	3,8
27	6680,00	6724	44	0,6
28	6810,12	6800	10,12	0,14
29	8250,52	8225	25,52	0,3
30	8340,18	8330	10,18	0,12
Error average				1,7

Table 1 shows various illuminance values in lux captured by the BH170 sensor. The data was randomly collected and tested at different levels of illuminance, either from sunlight exposure or artificial lighting such as LED lamps. It can be concluded that the obtained MAPE value is 1.7%; in other words, the accuracy reaches 98,3%.

Table 2. Result of temperature testing

No	DS18B20 °C	Thermometer °C	Difference	Error (%)

1	37,86	37,8	0,06	0,15
2	38,00	37,8	0,2	0,5
3	40,13	41	0,87	2,1
4	42,12	42	0,12	0,28
5	36,28	36,7	0,42	1,14
6	35,72	36,7	0,98	2,6
7	34,74	33,8	0,94	2,7
8	30,90	29,6	1,3	4,3
9	18,80	18,5	0,3	1,6
10	30,90	29,5	1,4	4,7
11	27,60	27,6	0	0
12	28,50	28,2	0,3	1,06
13	30,00	29,8	0,2	0,6
14	31,00	30,7	0,3	0,9
15	34,50	33,8	0,7	2,07
16	42,10	41	1,1	2,6
17	43,64	42,9	0,74	1,7
18	51,00	49,5	1,5	3,03
19	52,38	51,7	0,68	1,3
20	28,00	28	0	0
21	32,58	32	0,58	1,8
22	34,00	34	0	0
23	33,26	32,1	1,16	3,6
24	72,68	72,8	0,12	0,16
25	72,80	72,9	0,1	0,13
26	72,80	73,6	0,8	1,08
27	18,24	18,2	0,04	0,2
28	18,36	18,3	0,06	0,32
29	36,00	36,2	0,2	0,5
30	34,32	34,8	0,48	1,3
Error average				0,8

Table 4.2 shows several temperature measurements in Celsius captured by the DS18B20 sensor. The data was randomly collected and tested using various temperature triggers, either from room temperature or other triggers like hot water. It can be concluded that the obtained MAPE value is 0.8%. In other words, the accuracy reaches 99,2%.

Table 3. System Test

Commands from the software Arduino	**Light sensor (BH1750)**	**Temperature sensor (DS18B20)**	**I2C LCD**	**Relay module**	**Fan**	**Message Status**
Show data	ON	ON	ON	-	-	Display data
Turn on the relay	-	If temperature >30°C	ON	ON	ON	Turn on the fan
Turn off the relay	-	If temperature <30°C	ON	OFF	OFF	Turn off the fan

As explained in Table 1, it can be determined that the system testing is comprehensive: when the Arduino software commands the BH1750 and DS18B20 sensors to turn 'ON', these sensors will send signals to the Arduino, which, upon confirmation, will instruct the I2C LCD to display the detected data. If the I2C LCD shows a temperature > 30°C, the Arduino will send a command for the relay to turn 'ON', causing the relay to connect power from the power supply to activate the fan. Similarly, if the I2C LCD shows a temperature < 30°C, the Arduino will command the relay to turn 'OFF', cutting off power to the fan, thus turning it off. Therefore, it can be concluded that the overall system testing aligns with the programmed instructions.

3.2 System Testing on Objects

Observations were made on the number of branches and plant height with three different treatments. Each treatment will be carried out with LED, which allows the light exposure duration to be reduced from 14-18 hours to just 10-12 hours, with the fastest plant maturity occurring 25 days after planting, saving up to 25% of energy. Through this technology, various types of plants can be cultivated [12]. Researchers have different opinions regarding the light radiation (lux) needed by cayenne pepper plants during the vegetative stage, such as 2,528 – 4,287 lux [13]. The temperature sensor results for chili plants need to remain stable at 30°C [10]. The humidity needed for cayenne pepper plants is typically around 60 - 80%, which is used for optimal cayenne pepper cultivation [14]The purpose of each treatment is to determine how effectively the artificial lighting system created can achieve plant development.

1) First Treatment

This first observation is used to determine the development of chili plants under conditions of light intensity and temperature provided in an enclosed space. This test was conducted over 40 days (from January 20 to February 27, 2024) with an average light radiation exposure of 844.93 lux and a room temperature of 28.56°C.

Table 4. First Observation

Treatment 1	Averange per day	
	Plant height (cm)	Number of branches (units)
T1	0.32	2
T2	0.36	2
T3	0.21	2
T4	0.36	1

Table 4 shows the growth of four bird's eye chili plants under the first treatment, which involved light exposure in an enclosed space. From the measurement data collected from the first day to the 40th day, the average light intensity was 844.93 lux, and the average temperature was 28.56°C. The stem growth of the fourth plant remained fairly consistent at around 0.3 cm per day. In contrast, the stem growth of plants T1, T2, and T3 was quite consistent, averaging 2 branch nodes per day, except for T4, which had an average branch growth of 1 node per day. This inconsistency in T4 may have been due to inadequate care caused by the enclosed space, leading to poor air circulation or the plant being affected by disease or other issues related to spraying, such as pest control liquid, fertilizer dosage, soil acidity, and so on.

2) Second Treatment

This second observation is used to determine the development of chili plants under conditions of light intensity and temperature provided in an enclosed space with openings. This test was conducted over 40 days (from February 28 to April 4, 2024) with an average light radiation exposure of 977.16 lux and a room temperature of 28.41°C.

Table 5. Second Observation

Treatment 2	Averange per day	
	Plant height (cm)	Number of branches (units)
T1	0.34	2
T2	0.32	2
T3	0.3	3
T4	0.33	2

Table 5 depicts the growth of four bird's eye chili plants under the second treatment, which involved light exposure in an enclosed space with openings. From the measurement data collected from the first day to the 40th day, the average light intensity was 977.16 lux, and the average temperature was 28.41°C. The stem growth of the fourth plant remained fairly consistent at around 0.3 cm per day. In contrast, the stem growth of plants T1, T2, T3, and T4 was quite consistent, averaging 2 branch nodes per day. The presence of openings, created by leaving the box door open, increased the internal dimensions of the box, allowing the plants to take in more air. Additionally, the fan acting as a blower improved air circulation within the box, making it more controlled, as shown in Fig. 4.

Figure 4. Second treatment testing

3) Third Treatment

Table 6. Third Observation

Treatment 2	Average per day	
	Plant height (cm)	Number of branches (units)
T1	0.34	2
T2	0.32	2
T3	0.3	3
T4	0.33	2

This third observation is used to determine the development of chili plants under conditions of light intensity and temperature in an open space with direct sunlight. This test was conducted over 40 days (from January 20 to February 27, 2024) with an average light radiation exposure of 19,701.73 lux and a room temperature of 28.47°C.

Table 6 shows the growth of four bird's eye chili plants under the third treatment, which involved conventional exposure as a comparison. From the measurement data collected from the first day to the 40th day, the average light intensity was 19,701.73 lux, and the average temperature was 28.47°C. The stem growth of the four plants varied, with T1 and T4 growing 0.6 cm, T2 growing 0.4 cm, and T3 growing 0.5 cm. The branch growth of all four plants was fairly consistent at 1 branch node per day. However, around the 15th day, branch growth began to slow, and by the 38th day, the plants stopped growing altogether. This slowdown could be attributed to the open environment and the fact that the study was conducted during the rainy season. In contrast, chili plants are typically cultivated in the dry season. Additionally, the plants were more susceptible to issues such as pests, excessive soil moisture, and other factors. By the 40th day, the plants started to yellow and wilt.

Figure 5. Third treatment testing

3.3 Data Comparison

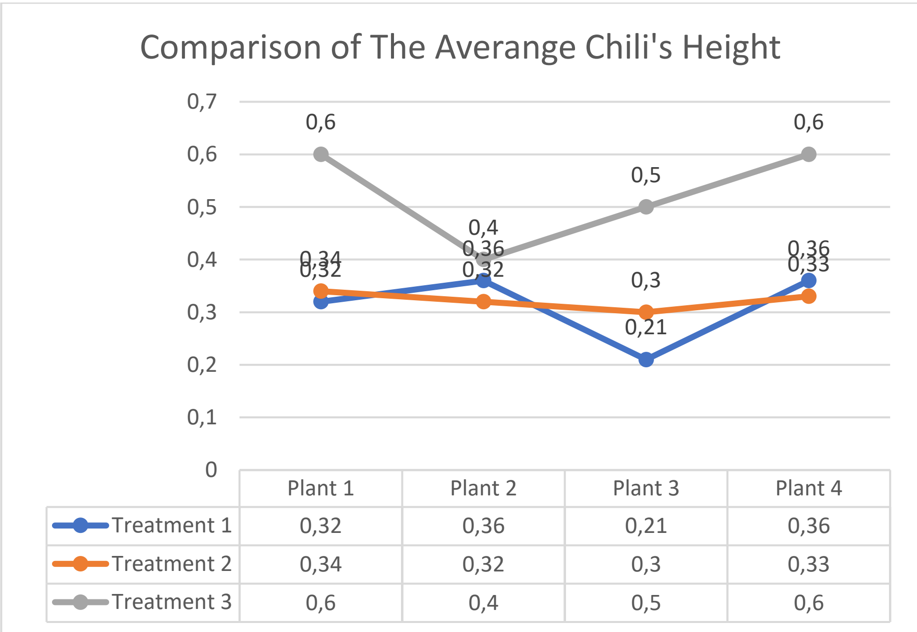
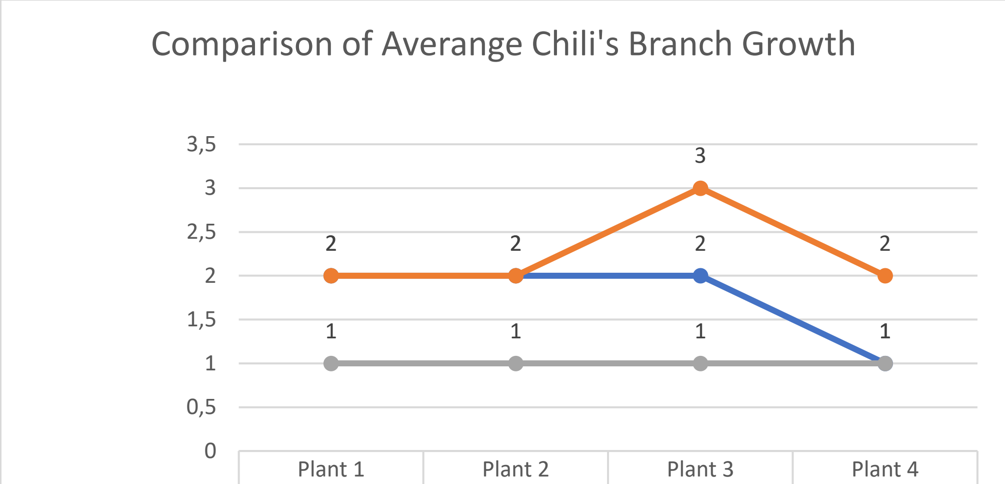


Figure 3. Comparison of the average chili's height

During the 40-day research period, the author obtained the average height data of chili plants for each treatment as follows, in the first treatment, the plants were given an average light intensity of 844.93 lux with a lighting duration of 12 hours using a 13-watt white LED lamp and an average temperature of 28.56°C, resulting in average plant growth of 0.32 cm (T1), 0.36 cm (T2), 0.21 cm (T3), and 0.36 cm (T4) per day.

In the second treatment, the plants were given an average light intensity of 977.16 lux with a lighting duration of 12 hours using a 13-watt white LED lamp and an average temperature of 28.41°C, resulting in average plant growth of 0.34 cm (T1), 0.32 cm (T2), 0.3 cm (T3), and 0.33 cm (T4) per day.

In the third treatment, the plants were given an average light intensity of 19,701.73 lux with a lighting duration of 12 hours in an open space (direct sunlight) and an average temperature of 28.47°C, resulting in average plant growth of 0.6 cm (T1), 0.4 cm (T2), 0.5 cm (T3), and 0.6 cm (T4) per day.



	Plant 1	Plant 2	Plant 3	Plant 4
Tratment 1	2	2	2	1
Treatment 2	2	2	3	2
Treatment 3	1	1	1	1

Figure 4. Comparison of average chili's branch growth

During the 40-day research period, the author obtained the average branch growth data of chili plants for each treatment as follows, In the first treatment, the plants were given an average light intensity of 844.93 lux with a lighting duration of 12 hours using a 13-watt white LED lamp and an average temperature of 28.56°C, resulting in average branch growth of 2 nodes (T1), 2 nodes (T2), 2 nodes (T3), and 1 node (T4) per day.

In the second treatment, the plants were given an average light intensity of 977.16 lux with a lighting duration of 12 hours using a 13-watt white LED lamp and an average temperature of 28.41°C, resulting in average branch growth of 2 nodes (T1), 2 nodes (T2), 3 nodes (T3), and 2 nodes (T4) per day.

In the third treatment, the plants were given an average light intensity of 19,701.73 lux with a lighting duration of 12 hours in an open space (direct sunlight) and an average temperature of 28.47°C, resulting in consistent average branch growth of 1 node per day for all four plants.

4. Conclusion

The design of this prototype consists of several parts: 220V electricity and a power supply as the voltage source, a light sensor (BH1750) to detect light radiation (lux), a temperature sensor (DS18B20) to detect temperature (°C), an Arduino Uno as the control system, a relay as a switch, a fan as an actuator (blower), and an I2C LCD 16x2 to display light and temperature data. The tool's casing is made of iron angles as the frame and white polycarbonate plastic as the cover. The lighting uses white daylight LEDs.

The testing results of the designed prototype show that it functions well in its operation. From the research conducted, it can be concluded that the greatest stem height increase occurred in the third treatment (without the device) with an average of 0.6 cm per day. However, on the 15th day, the plants began to slow down their growth, and by the 38th day, they had stopped growing. This could be due to the plants being in an open space and the research being conducted during the rainy season, making the plants susceptible to diseases or other issues such as pests and excessive soil moisture. By the 40th day, the plants started to yellow and wilt. On the other hand, the greatest branch increase occurred in the second treatment (using the device with the door open) with an average of 2 branch nodes per day. For further research, the author hopes that subsequent studies can be conducted until the harvest period and collaborate with relevant parties such as the agricultural faculty, the Faculty of Mathematics and Natural Sciences, and the chili farmer community to study the characteristics of the plants more in-depth.

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