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"Utilization of Varying Colors of Light Emitting Diodes in Vertical Farms for *Solanum lycopersicum* (Tomato)"

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ABSTRACT: In response to climate change and significant decreases of arable land in developing nations, vertical farming has emerged as a suitable alternative to the conventional method of farming with its use of modern technologies such as LED lights. Since previous literature on this subject had mainly focused on the effects of blue and red lights concerning plant growth, this research paper involved 620 nm (pink light), 550 nm (green light), and the combination of the colors in the color spectrum (white light) to expand the scope of the study. The facilities used for the experiment were a multiple-row vertical setup and a raised bed garden for the conventional setup. These setups were created using recyclable wood and furniture. Measuring tapes and finger-counting were utilized to detail the average height and number of leaves of plants within a specified group. One-way analysis of variance and repeated measures variance was used to show the variance or consistency of each group and significant differences between all groups. The results had depicted pink-colored LEDs to have yielded the best results by the end of the experiment with an average plant height of 10.39 cm and an average leaf number of 3.1. Overall, the vertical farming setups outperformed the conventional farm setup in terms of both mean plant height and number of leaves.

KEYWORDS: vertical farming; conventional farming; light-emitting diodes; tomato plants; effects of light on plants

INTRODUCTION

Population count is a dominant parameter for local authorities in assessing and determining the needs of its citizens. However, the current growth rate, based on recent years, has led to shortages in some nations, where the supply of these essentials could no longer meet the demand, most notably in the food industry. A paper by Banerjee and Adenaeuer (2014) stated that 60% more than today's food production will have to be maintained by the year 2050 if this criterion is maintained. At the same time, an extra one million hectares of arable land would need to be converted to fields by the same year (Zhang et al., 2018). The extent of this situation has become both costly and devastating, given that uncontrollable urbanization and environmental factors — such as climate change — already inflict existing issues regarding land usage (Mariappan & Zhou, 2019). Unfortunately, the hazards of food security tend to be enough in affecting a country's overall socio-economic growth. Food insecurity, particularly due to high demand and natural hazards, remains one of the many strains of developing nations today. In India, where cultivation is the backbone of the economy, the threat of shortages, failed harvests, and farmers' suicide has been widespread for several decades (Mishra & Nayak, 2004). In addressing these concerns, many heads of state around the world were prompted in keeping their food sector future-proof through vertical farming. The Association for Vertical Farming (2016) defined this as a style of cultivation that relies on stacked layers, as opposed to rows of fields in traditional methods. Because vertical farming takes place within buildings and warehouses, operators have more control over their environment through various systems (Sillitoe, 2021).

As a method of encouraging the utilization of vertical farms as sources of food production, an idea of a miniature vertical garden in conducting tests on other available colors through light-emitting diodes was conceptualized. Firstly, small-scale vertical farms are affordable and can be centered within communities as shared gardens in highly urbanized areas. Secondly, the study on other colors on the electromagnetic spectrum and their effect on plant growth remains a significant information gap. The addition of these findings could potentially result in flexible solutions that provide less financially able countries to receive similar services.

The Concept of Vertical Farming

Vertical farming consists of multiple stacked layers in growing produce. They usually coincide within tall buildings and warehouses that enable a more controllable setup as compared to traditional methods (Kalantari, et al., 2017). The cultivation setup is mainly built with a closed environment and is easily controllable through the additions of artificial lighting sources. Veerappan & Jagadeesh (2014) described the method as a combination of a greenhouse and a skyscraper in cultivating crops through artificial sunlight. Unlike traditional farming, it is purposely designed to take advantage of electricity in controlling many of its parts (Banerjee, 2014). Based on several studies, vertical farming was tested for the purpose of proving its capabilities.

Light-Emitting Diodes

Light-emitting diodes are small-sized artificial light sources that create a substitute for sunlight by displaying different waves of visible light. Mandala (2018) defined this as light energy being displayed from a series of wavelengths, also known as the electromagnetic spectrum. Those outside the visible light spectrum may cause negative effects such as sunburns from the sun's non-visible, ultraviolet light. Light-emitting diodes, however, stop this phenomenon because of the ability to modify and fine-tune the wavelengths it emits. Previous studies have found that setting these wavelengths to present specific colors does cause an impact on the plant's overall structure. Reddish colors appeared to be the most efficient due to their easy absorption by chlorophylls, which are found on the leaves of plants (Massa et al., 2008). In Japan, another study determined that either red or blue lights are beneficial for leaf growth, however, resulting in compromises regarding its yield (Ohashi-Kaneko et al., 2007).

Overall Plant Growth

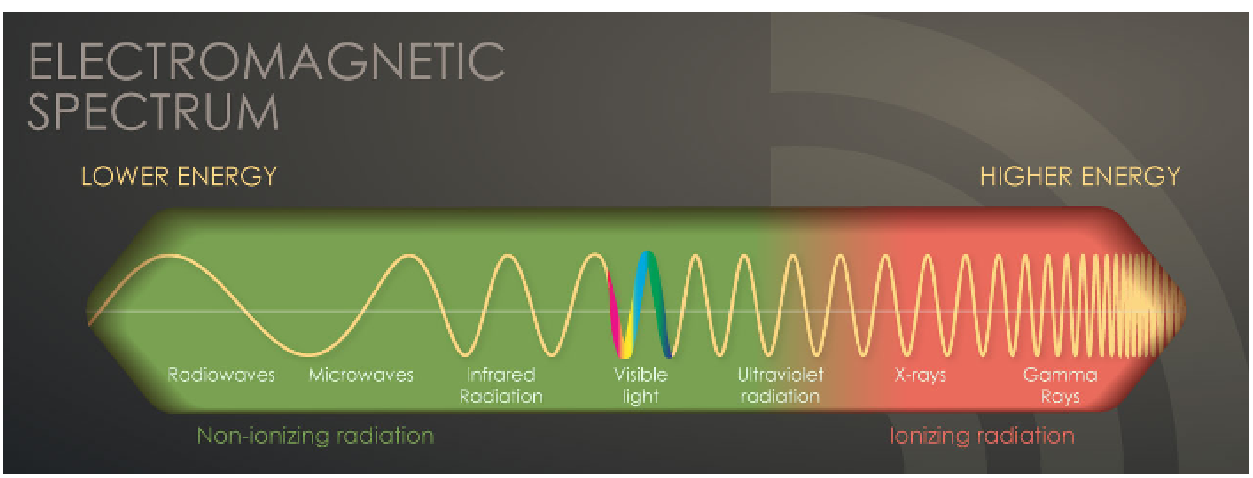
Apart from the number of products made, farmers closely monitor the overall appearance of their crops. According to Runkle (2011), plant growth is a circumstantial trait that relies on different factors, thus making it a dependent variable. Farmers rely on specific indicators in diagnosing their plants' morphological structure, particularly regarding the crop canopy (Lee & Ehsani, 2009). Such as nutrient deficiency, the physical structure can solely present deficiencies in different criteria, mainly portrayed as delayed development and discoloration (McCauley et al., 2011). Pennisi (2019) outlines the need for adequate amounts of lighting — reiterating the vulnerability of every living organism to strong amounts of sunlight, which would expose them to ultraviolet light. In vertical farming, because plants are continuously under heavily controllable environments, it is expected that all those within the system have similar qualities (Laursen, 2020).

Theory of Electromagnetic Waves

All forms of light are made of electromagnetic waves, which range in terms of energy levels, and thus are categorized based on their respective wavelengths and frequencies in the electromagnetic spectrum (Simmons, 2007). Figure 1 illustrates the placements of each group in the range.

Figure 1

Electromagnetic Spectrum Chart



Based on the above figure, longer wavelengths are located on the left and shorter wavelengths on the right. These wavelengths are inversely proportional to the energy. In context to the current research study, plants read a small array of the non-ionizing group known as visible light. This group has longer wavelengths and low energy levels hence unable to alter any physical matter significantly. According to Fondriest Environmental (2014), visible light in plant growth is depicted as photosynthetically active radiation (PAR), scientifically noted as the most effective field in stimulating photosynthesis. Thus, it can be presumed that light-emitting diodes displaying 100% visible light will be both safer and more effective than sunlight with only 42%.

Statement of the Problem

This study aims to check for significant findings after doing the treatments (experiments) on tomato (*Solanum lycopersicum*) plants. The researchers plan to look at the overall yield and physical structure of the tomato plants after the treatment/s and experiment/s have been done. As of the time of writing, there is an insufficient number of papers that directly compare vertical farm setups to a conventional setup to see how they compare in terms of plant growth and the number of leaves.

Scope and Limitations

Work-from-Home Setup: The continuation of community quarantine in the Philippines made any physical interaction impossible. In lieu of this, the hands-on experiment proper of the study was limited to only selected researchers and their respective residences. The collected data was shared through online messengers, group chats, and virtual meetings as other members took part in the analysis of data.

Material Procurement: The materials necessary for the experiment were acquired through online stores due to quarantine restrictions.

Scope of Assessment: This study focused on using different colors of LED lights through a vertical farm setup, in contrast to a traditional garden. This research lasted for approximately two months. Everything was evaluated from the researchers' own residences, given the limitations of community quarantine. The colors of the different light-emitting diodes were pink, green, and white.

Significance of the Study

The combined effects of urbanization and negligence in farmlands around the world have prompted many governments and private sectors to intervene. During this time of a pandemic, people were reminded about the importance of food security and quality of life. In promoting both newer and cleaner methods of cultivation, the needs of the people are once again being answered, though just not swift in terms of action. The study was aimed to determine the effect of three treatments utilizing LED lights, a setup involving natural sunlight, and a group with no lights. The recording of various categories of data from different settings in the independent variables was also conducted. It took place over a period of twenty days.

Availability: Utilizing a vertical system of cultivation is still relatively new and still unknown in some regions of the world. Farmers around those areas continue to feel the brunt of uncontrolled urbanization and climate change. The current study's goal in finding more information on other colors of LED might contribute towards further popularizing the topic. Those in developing regions might be able to see more benefits towards growing produce using artificial light and may end up having some of their own for their citizens. Furthermore, this meant possibly a change in terms of food insecurity of a specific place.

Body of the Research: While vertical farming continues to popularize in developing regions, newer discoveries are being created at a rapid pace. This swift transition is of no concern, for it is meant to solve others previously mentioned above. The current study was of no exception either, experimenting on a setup aimed for clear observations of artificial lights on plants. While it was not expected to blow up overnight, the information might still potentially be applied towards finding a maximized method of vertical farming, one which leads to more effective results. Adding to that, refining newer technologies might also lead to further popularity, usability, and more options for different communities. For example, in the past when smartphones were used as only a necessity, currently the options range from budget to flagship. Judging this fact, the added attention might just bring vertical farming more towards convenience.

METHODOLOGY

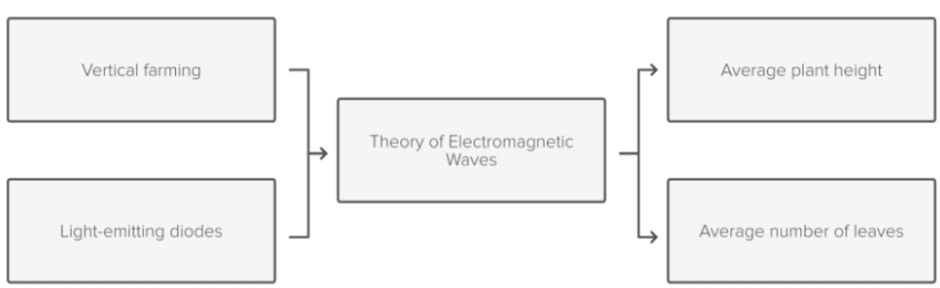
Conceptual Framework

Based on the theory, it is assumed that the LEDs utilized in vertical farming will influence the average plant height and the average number of leaves. The relationship between the variables and the theory was discussed.

All sources of light are reflected on electromagnetic waves of varying intensities and wavelengths as illustrated in the electromagnetic spectrum, which is divided into two parts: ionizing and non-ionizing radiation (CDC, 2015). Ionizing radiation contains the ability to alter physical matter, while non-ionizing radiation has only the energy to generate heat at most (Briones, 2021). Sunlight, a natural light, contains a static figure of 42% visible light, while light-emitting diodes within vertical farms could be manipulated to produce 100% visible light, whether as a spectral (singular) color or a color mixture (Volchko, 2018), in which can predict that light-emitting diodes could be more effective towards plants in how they grow and how many are able to germinate. Figure 2 illustrates the relationship.

Figure 2

Conceptual Paradigm



In the discussion of Runkle (2017) on his experiment of blue and red light on Salvia Vista Red plants, there is evidence that different colors and their respective wavelengths alter how plants behave in specific criteria. Understanding how the colors of light relate to their composition and placements in the electromagnetic spectrum will contribute to the data analysis following the experimentation (Fondriest Environmental, 2014; NASA, 2016).

Research Design

An experimental design was conducted in differentiating the values of plant height and leaf number between small-scale vertical setups with differing LED colors, as opposed to setups using either natural sunlight or without any lighting in general. A single factorial design took place as the type of experimental research to be used. Factorial research papers authorize the observation of effects and interactions from two or more independent variables called factors (Lavrakas, 2008).

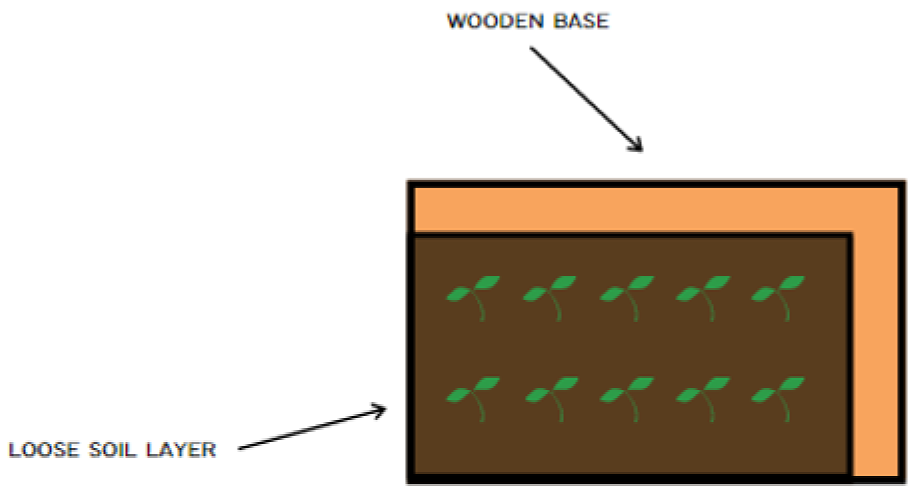
This research study implemented two control groups and three independent experimental groups. The positive control group consisted of samples affected by the natural sunlight, the negative control group included samples not affected by any light source, while the experimental groups included manipulated samples (Cherry, 2020). In the context of this experiment, the positive control group was a raised bed tomato garden, the negative control group was a row of plants grown with no lighting, and the experimental groups consisted of a single small-scale vertical farm.

Procurement of Materials

The raised bed served as the sole control group of the research study. Pre-existing pieces of wood served as the base material in creating a three-by-four-foot frame of the raised bed tomato garden, which contains the topsoil and will prevent erosion during inclement weather. The wooden structure must be in a place that receives ample amounts of sunlight. Tomato gardens must receive at least six hours of natural light and be situated adjacent to a water source (Cardinez, 2013). Moreover, the raised bed tomato garden was placed on top of an open area of existing soil, which requires the removal of runner grasses within the specific area. Afterward, it was filled with loose soil, which is depicted in Figure 3.

Figure 3

Illustration of the Positive Control Group

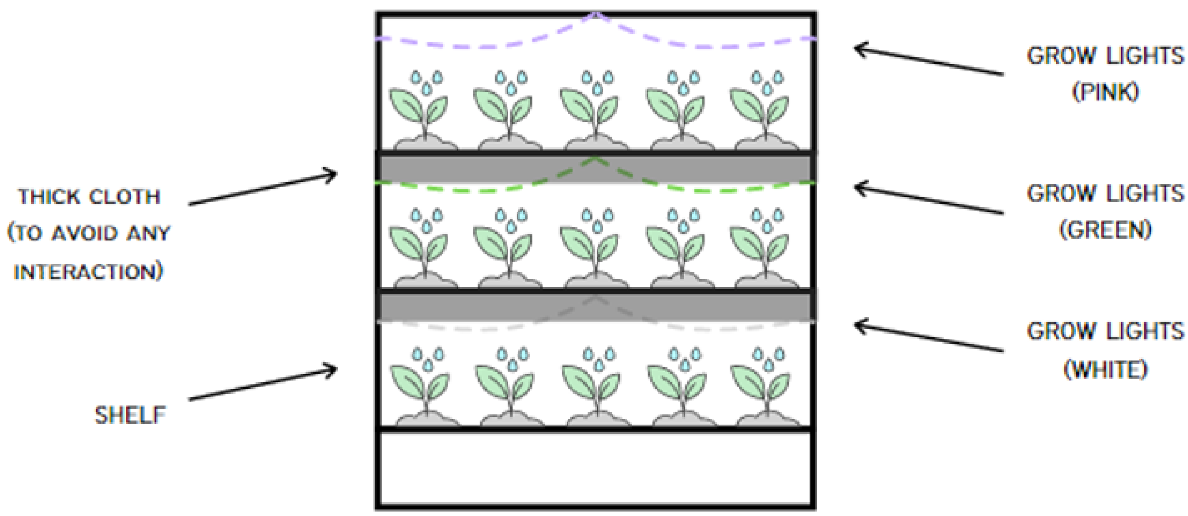


On the other hand, vertical farms are cultivational setups within either a skyscraper, warehouses, or any closed area containing vertically inclined layers (Despommier, 2010 as stated in Ali & Srivastava, 2017). Three of these setups were equipped with LEDs, which are artificial light sources that are both energy-saving and easily controllable in emitting visible light (Opel et al., 2015). In this case, a small-scale vertical setup was representing the three independent groups, one for each row. As mentioned, different sets of plants were subjected to pink, green, and white light respectively, while one set was not exposed to light, which was expected not to grow due to photosynthesis being unable to occur due to the absence of sunlight (Smestad, 2021).

Racks with four rows served as the main material for the base of the vertical farm. Three strings of LED grow lights were bought and placed on the top of each group (Monostori et al., 2018). These were set to pink at the top, green in the middle, and white at the bottom. To avoid any interaction between two or more light sources, thick pieces of cloth or mats were attached, and any windows or openings that may expose the samples to external lighting were covered. Two covers were placed in between the first and second, the second and third groups, and the third and fourth groups, while the negative control group was grown separately. The negative control group will be separately managed by another researcher. Fifty plants will then be divided into five groups of ten. Each represented one experimental group to be determined based on the floor space of the racks themselves. The parts and overall structure of the vertical setup are shown in Figure 4.

Figure 4

Illustration of the Experimental Groups

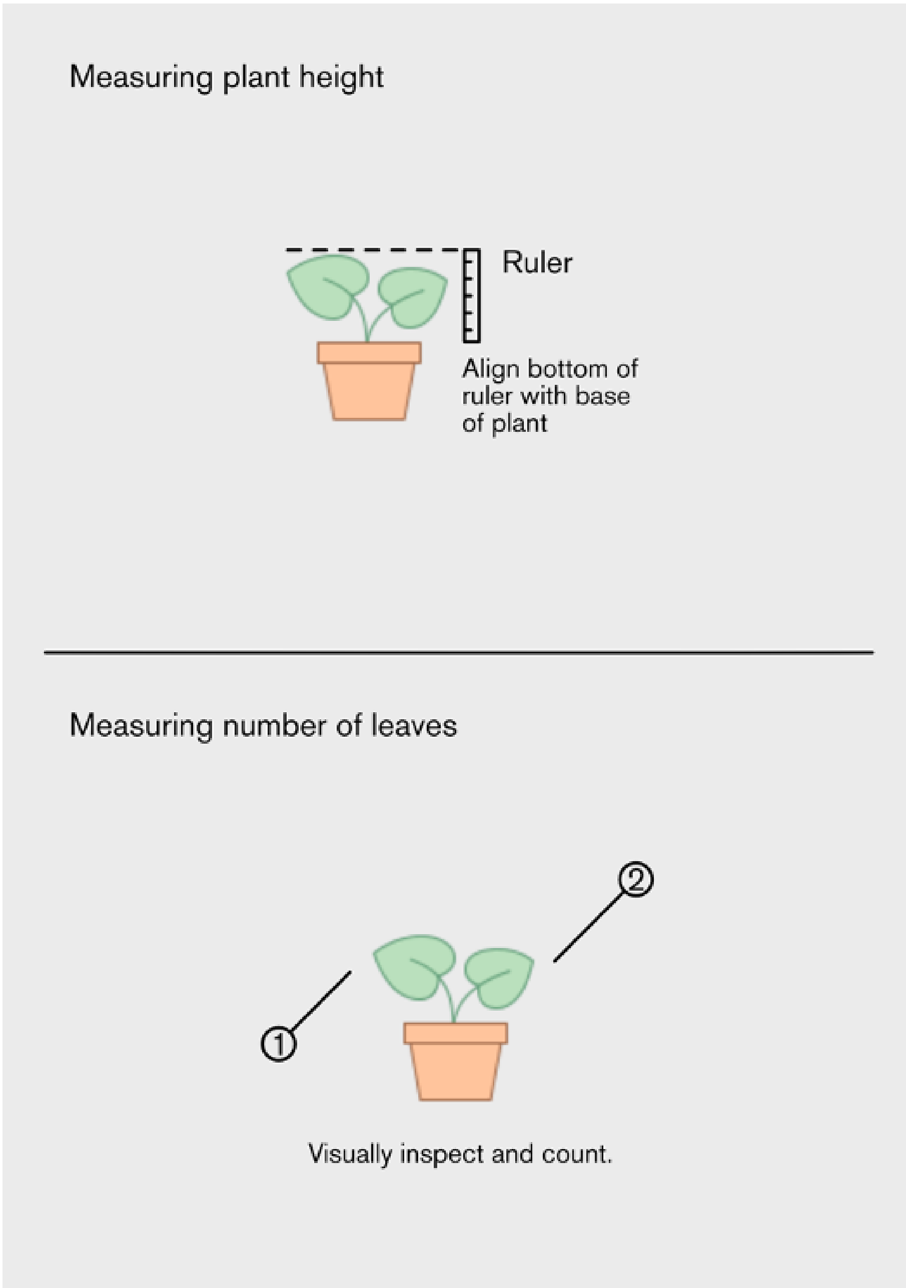


Instruments

The height of each plant is part of the main basis in determining the overall crop quality (Runkle, 2011). In measuring plant height, a measuring tape was used, and the height was measured in inches (in). Brightness (also known as electron volts) was measured using the Arduino Science Journal (Arduino LLC, 2020) application which was downloaded on the researchers' mobile devices. The application is capable of measuring light in lux with the use of the ambient light sensor option. In essence, the brightness measured using this application is the amount of light the plant is exposed to. The three assigned researchers are required in having possession of one within their own residence. Following the tenth day and the twentieth day, each of the fifty plants involved were temporarily placed out of their respective setups for the measurement of this specific category.

Figure 5

Process on Measuring Plant Height and Number of Leaves

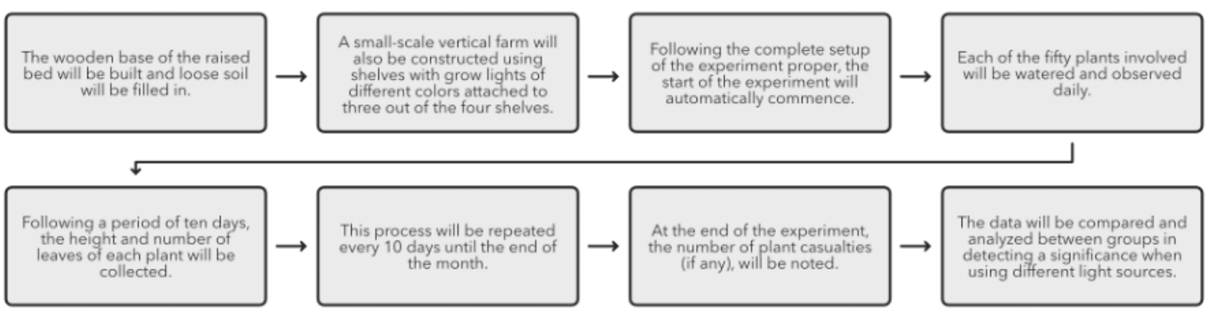


Data Gathering Procedures

The experiment began following the planting of all tomato seeds. During the first few days, all the five independent groups were watered daily with a few sprays from a spray bottle. Seeds at the first stage of germination require only the surface layer of the soil to be moist (Espoma, 2016). Each setup also received similar amounts of light per day. Thus, all grow lights situated in the vertical farm will be turned on during dawn and switched off during dusk respectively. There is a need for all fifty plants to have a day-night cycle, otherwise, it will result in incomplete development or halted growth (Gerard, n.d.). This amounts to a total of twelve to thirteen hours of light daily in all groups. Please refer to Figure for the flowchart of the whole process.

Figure 6

Data Collection Flowchart



On the tenth day, the height and number of leaves of each plant were monitored as displayed in Table 1. As mentioned, plants were taken out and placed back from their respective setups one at a time. In case specific plants have yet to emerge, they were labeled with a value of zero. Afterward, the current data was used in finding the mean height and leaf count of all ten seedlings in each of the five groups. The test determined whether each plant is growing at a relatively consistent rate. The formula "m = sum of the total / 10" was utilized. The denominator, being ten, was consistent regardless of if all ten were to sprout or not.

Table 1

Organizer of the Raw Data

	10 Days	20 Days
Control Group	- mean leaf number - mean height	- mean leaf number - mean height
Experimental Group 1 (Pink)	- mean leaf number - mean height	- mean leaf number - mean height
Experimental Group 2 (Green)	- mean leaf number - mean height	- mean leaf number - mean height
Experimental Group 3 (White)	- mean leaf number - mean height	- mean leaf number - mean height
Experimental Group 4 (No light)	- mean leaf number - mean height	- mean leaf number - mean height

The seedlings received the same treatment from the eleventh up to the twentieth day. Most of the seedlings were expected to show signs of further germination, most notably the sight of roots and a stem. Therefore, those specific plants were given slightly more water daily, which will be poured from a watering can for one to two seconds. In checking whether enough water was poured, the three researchers used a method, in which their thumbs are burrowed one inch into the topsoil to check moisture levels (Espoma, 2016). For those seedlings that are yet to grow, they were watered the same way as during the earlier days, until the same signs appeared. Every other instruction remained consistent for the rest of the experiment proper. Following the recording for the twenty days, the experiment ended. All values were involved in comparisons between one another in judging the efficacy of different light sources between all the groups.

Data Analysis

The collected data was analyzed using the single-factor analysis of variance (ANOVA) method with the aid of SPSS (IBM Corporation, 2020). The statistical treatment was utilized to test whether any significant difference between groups in the experimentation is present. Additionally, it is most appropriate for factorial designs.

Finding the mean of these two factors will give the researchers an idea of the general effectiveness of each treatment and will act as a supplementary measure of said treatments. The Analysis of Variance (ANOVA) was also executed as the statistical treatment for the second research question. These questions aim to form a relationship between the setup used and the plant height and number of leaves of the tomato plant samples. In definition, ANOVA checks if any significant difference between two or more independent groups had taken place (Singh, 2018). As presented in Figure 5, the experiment compared the functionality of plants between the five different groups through the collected data being leaf count and mean height. Moreover, the independence of observations was present, as each group was observed and recorded separately on a ten-day-basis.

RESULTS AND DISCUSSION

As a reference, there are two factors recorded separately within two data collection checkpoints for this experiment. Therefore, the single-factor ANOVA test was repeated four times. Additionally, to determine that the plants had significantly changed between measurement checkpoints, four additional repeated measures ANOVA tests were done. This is proven crucial because both the mean and variance were compared amongst one another during the analysis, in which a higher number will equate to being better in both instances. The goal of the study was to inscribe the highlights of this research as an additional model in gardening and other methods of cultivation. The following questions that were answered are as follows:

The benefit of conventional farming over vertical farming for overall plant height

Table 1.1

ANOVA Average and Variance of the Overall Plant Height (Day 10)

Groups	***Count***	***Sum***	***Average***	***Variance***
Conventional	10	35.8	3.58	0.12
Vertical, No Light	10	66.8	6.68	0.33
Vertical, Pink Light	10	36.5	3.65	0.26
Vertical, Green Light	10	42.9	4.29	1.24
Vertical, White Light	10	31	3.1	0.42

Table 1.2

ANOVA Average and Variance of the Overall Plant Height (Day 20)

Groups	***Count***	***Sum***	***Average***	***Variance***
Conventional	10	52.3	5.23	0.17
Vertical, No Light	10	68.8	6.88	0.44
Vertical, Pink Light	10	103.9	10.39	4.59
Vertical, Green Light	0	0	-	-
Vertical, White Light	10	56.7	5.67	0.88

As shown in Table 1.1, the average plant height during the tenth day of experimentation is highest at 6.68 centimeters with the second control group and lowest at 3.1 centimeters with the vertical farm under the influence of white light. Moreover, the remaining groups have ranged from three to four centimeters in growth. This specific data was calculated through the sum of all plant heights in a specific group and divided by its respective quantity.

The researchers have also observed a significant shift in the overall growth rate in the twentieth day of experimentation. According to the data in Table 1.1, the second control group had failed to show much development and only grown by two centimeters as a result.

Additionally, the entire vertical farm group under green light had perished in-between the experiment period. Thus, a value of null was received following the data analysis. Nonetheless, the other involved groups were recorded with a positive growth rate. The vertical farm group under pink light had the highest result with a value of 10.39 centimeters and the conventional group had the lowest mean with 5.23 centimeters. Overall, it is evident from the analysis of the variance table that the growth of the conventional group was surpassed by all living vertical farm groups in the second checkpoint.

Table 1.3

Multivariate ANOVA of the Overall Plant Height

Effect		***Value***	***F***	***Hypothesis df***	***Error df***	***Sig.***
Day	Pillai's Trace	0.557	56.516b	1	45	0
	Wilks' Lambda	0.443	56.516b	1	45	0
	Hotelling's Trace	1.256	56.516b	1	45	0
	Roy's Largest Root	1.256	56.516b	1	45	0
Day * Groups	Pillai's Trace	0.895	95.437b	4	45	0
	Wilks' Lambda	0.105	95.437b	4	45	0
	Hotelling's Trace	8.483	95.437b	4	45	0
	Roy's Largest Root	8.483	95.437b	4	45	0

The value for Wilks' Lambda in the multivariate table is 0.443, suggesting that roughly half of the variance in the plant height is explained using different setups in growing the tomatoes. Additionally, the significance value rounds off to zero, meaning that this value is statistically significant.

Effects of LED color on the growth of tomato plants between vertical farming set-ups

Table 2.1

Analysis of Variance Table of the Overall Plant Height for Vertical Farming Setups (Day 10)

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F-crit***
Between Groups	11.875	3	3.958333333	14.39393939	4.37725E-12	2.866265551
Within Groups	9.9	36	0.275			

Table 2.2

Analysis of Variance Table of the Overall Plant Height for Vertical Farming Setups (Day 20)

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F-crit***
Between Groups	164.01075	4	41.0026875	26.18450312	7.62952E-07	2.975154
Within Groups	54.807	35	1.565914286			
Total	218.81775	39				

As shown in Tables 2.1 and 2.2, the p-values ($p < 0.05$) from the data analysis merit a statistically significant effect of varying light sources towards certain behaviors of tomato plants seen during the experimentation. These indications will be furtherly conceptualized in the Discussion section.

Another key reference point is the mean of the plant height in each group, which was interpreted in answering the previous question. For full context, the data collected included both positive and negative progress throughout the twenty-day period. The vertical farm with pink light had experienced a highly significant increase in average plant height from 4.29 cm to 10.39 cm, while the vertical farm with no light only grew by around two centimeters during the same timeframe.

Table 2.3

ANOVA Average and Variance of the Plant Height for Vertical Farm Setups (Day 10)

Groups	***Count***	***Sum***	***Average***	***Variance***
Vertical, No Light	10	66.8	6.68	0.339555556
Vertical, Pink Light	10	36.5	3.65	0.260555556
Vertical, Green Light	10	42.9	4.29	1.247666667
Vertical, White Light	10	31	3.1	0.428888889

Table 2.4

ANOVA Average and Variance of the Plant Height for Vertical Farm Setups (Day 20)

Groups	***Count***	***Sum***	***Average***	***Variance***
Vertical, No Light	10	68.8	6.88	0.446222222
Vertical, Pink Light	10	103.9	10.39	4.592111111
Vertical, Green Light	0	0	-	-
Vertical, White Light	10	56.7	5.67	0.880111111

Aside from the plant height, the average number of leaves shown in Tables 2.3 and 2.4 also serves as the main category of overall plant growth. During the first checkpoint, the treatment with pink LEDs had a mean of 3.1 leaves, followed by the treatment with white LEDs with a mean of two leaves and the treatment with green LEDs with a mean of 1.9 leaves. The treatment with no LEDs had the lowest mean of 1.7 leaves. The researchers had also observed a similarly slight shift in the data of the second checkpoint. The treatment with pink LEDs remained on top with a mean of 11.8 leaves, followed by the treatment with white LEDs with a mean of 4.6 leaves and the treatment with no LEDs with a mean of 1.9 leaves. As mentioned earlier, the plants under the treatment with green LEDs had completely died off.

Table 2.5

Multivariate ANOVA of the Plant Height for Vertical Farm Setups

Effect		***Value***	***F***	***Hypothesis df***	***Error df***	***Sig.***
Day	Pillai's Trace	0.481	33.377b	1	36	0
	Wilks' Lambda	0.519	33.377b	1	36	0
	Hotelling's Trace	0.927	33.377b	1	36	0
	Roy's Largest Root	0.927	33.377b	1	36	0
Day * Groups	Pillai's Trace	0.897	103.979b	3	36	0
	Wilks' Lambda	0.103	103.979b	3	36	0
	Hotelling's Trace	8.665	103.979b	3	36	0
	Roy's Largest Root	8.665	103.979b	3	36	0

The Wilks' Lambda value of 0.103 for Day Groups suggests that roughly 90% of the variance in the plant height for the vertical setups throughout the whole experiment can be explained by the use of a different color of the LED. Additionally, the significance value is 0, meaning that the values in this table are statistically significant.

Table 3.1

Analysis of Variance Table of the Number of Leaves for Vertical Farm Setups (Day 10)

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	11.875	3	3.958333333	14.39393939	2.53945E-06	2.866265551
Within Groups	9.9	36	0.275			
Total	**21.775**	**39**				

Table 3.2

Analysis of Variance Table of the Number of Leaves for Vertical Farm Setups (Day 20)

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	37.8	3	12.6	12.1784386	3.63597E-05	2.975154
Within Groups	26.9	26	1.034615385			
Total	**64.7**	**29**				

As shown in tables 3.1 and 3.2, the difference in the number of leaves for vertical farm setups is statistically significant based on the respective p-values. Altogether, the plants treated with pink LED lights were interpreted to contain the best results among all five treatments.

Table 3.3

ANOVA Average and Variance of the Number of Leaves for Vertical Farm Setups (Day 10)

Groups	***Count***	***Sum***	***Average***	***Variance***
Vertical, No Light	10	17	1.7	0.233333333
Vertical, Pink Light	10	31	3.1	0.544444444
Vertical, Green Light	10	19	1.9	0.1
Vertical, White Light	10	20	2	0.222222222

Table 3.4

ANOVA Average and Variance of the Number of Leaves for Vertical Farm Setups (Day 20)

Groups	***Count***	***Sum***	***Average***	***Variance***
Vertical, No Light	10	28	28	0.622222222
Vertical, Pink Light	10	19	1.9	0.544444444
Vertical, Green Light	0	0	-	-
Vertical, White Light	10	4.6	4.6	1.822222222

Table 3.5

Multivariate ANOVA of the Number of Leaves for Vertical Farm Setups

Effect		***Value***	***F***	***Hypothesis df***	***Error df***	***Sig.***
Day	Pillai's Trace	0.74	102.400b	1	36	0
	Wilks' Lambda	0.26	102.400b	1	36	0
	Hotelling's Trace	2.844	102.400b	1	36	0
	Roy's Largest Root	2.844	102.400b	1	36	0
Day * Groups	Pillai's Trace	0.886	93.422b	3	36	0
	Wilks' Lambda	0.114	93.422b	3	36	0
	Hotelling's Trace	7.785	93.422b	3	36	0
	Roy's Largest Root	7.785	93.422b	3	36	0

The Wilks' Lambda value of 0.114 for Day Groups suggests that roughly 89% of the variance in the number of leaves throughout the whole experiment can be explained by the use of a different color of LED. Additionally, the significance value is 0, meaning that the values in this table are statistically significant.

As aforementioned, the efficacy of a specific setup on a plant for this research study is determined by the plant height and the number of leaves. Based on data from the twentieth day of the experiment, all living vertical farm groups had surpassed the conventional group in both variables. This concludes that vertical farming provides better results in overall plant height than conventional farming. Therefore, it is also more advantageous. From the four vertical farming setups, the plants under pink light were observed as the most effective mode because of maintaining a lead in both categories.

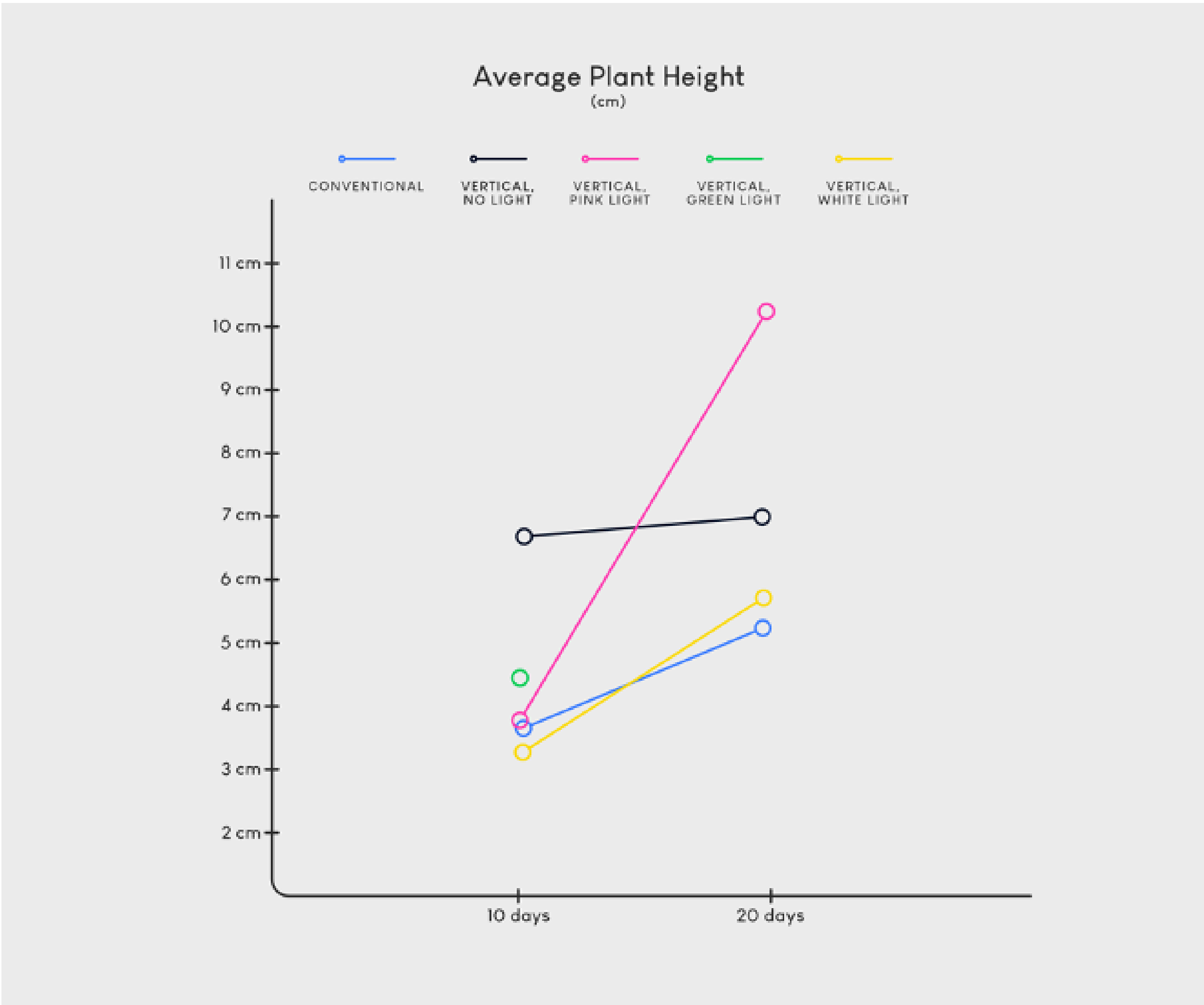
Discussion

As explained in the previous section, the values situated within the mean height category are substantially higher for groups located on the vertical garden as opposed to the conventional setup. However, a few exceptions were observed by the researchers. The control group with no light source, despite being recorded with the most plant growth during the tenth day of the experiment, had failed to sustain a similar rate by the end of the twenty-day period. Instead, all the occupying plants were found to have perished with a seemingly overstretched stem. Evidently, these details support the presence of a phenomenon known as the shade-avoidance syndrome, by which tall and spindly plants divert resources from organs to their stem in response to extended neglect from sunlight (Ballaré & Pierik, 2018).

In relation to fact, tomato plants have a specific growth limit that results in their particularly low leaf rate. The concept, however, was opposed upon close inspection that the group under pink lights had a higher number of leaves, while its average height was lower than the conventional farm. This specific finding does not necessarily contradict this fact, but it does prove that the tomato plant was healthy by comparing its average height to its average number of leaves. Comparatively, the conventional group was recorded with a higher value in mean height, although the data regarding its average number of leaves cannot back up that the tomato plant was healthy since a good ratio between its height and number of leaves was not achieved.

Figure 6

Progression of the average plant height from the 10-day to 20-day mark



At the end of the experimentation, some results have significantly shifted. The vertical farm under pink light had the steepest growth rate in the average height, while the conventional the farm was for its constant sluggish growth. Parallel to previous researchers, these results have linked the distinctive pink color to the overall efficiency of produce within vertical gardens. The color is produced from the combination of red and blue wavelengths (Robinson, 2021), which are the two most studied colors for plant growth using artificial light sources. Hence, this proves a conclusion that vertical farms can deviate from conventional one-color setups and utilize mixtures of effective production.

Unsurprisingly, the vertical farm with no lights did not show consistency by the second checkpoint. This was expected with facts that plants living under an unlit environment would only survive in an interval of four to twenty days. Low light plants can go from twelve to twenty days, while those lighter dependent are likely for about four to ten days. Together, it becomes highly recommended for vertical gardens to be equipped with proper artificial lighting and under a specific setting. From the data analysis conducted by the researchers, diverging from this concept is repeatedly linked to plants being unable to reach their maximum potential growth.

The provided question was answered with the statistical analysis of the raw data from the previous chapter. With the utilization of one-way analysis of variance, it showed the presence of a significant difference of plant growth in both categories, which is parallel to the concept of varying light sources substantially altering the potential outcome of a group of plants. Although, despite all five groups being subjected to their designated treatments within the same time, null and negative values were recorded in the end. However, this specific information has simultaneously provided the involved researchers with written proof of a specific setup as incapable of producing reliable progress crucial for producing fruit.

All produced colors of artificial light in the experiment were presented through differing levels of light energy. It is possible that the growth of tomato plants in both fields is directly proportional to the presented light intensity (Rezazadeh, 2018). Else, the stems tend to stretch and die. Other relevant studies have also stated the importance of the ability of certain plants in light absorption. This capability has been linked to determining how the behaviors of plants eventuate. Green light is recognized as being important for plant growth (Massa et al., 2008). However, plants are also simultaneously most hesitant in absorbing green light waves (Wollaeger, 2014). Thus, it appears that continuous exposure to only green light may not be good for tomato plants in the long run.

Through the scientific processes of plants, the shade-avoidance syndrome stated earlier can be further applied. The rapid growth experienced by the group under pink light may also be affiliated with the insignificance of needing to stretch itself because of its given ample light (Ballaré & Pierik, 2018). In contrast, the control group with no given light sources had stretched as an attempt to absorb the lightest it could find. This theory was witnessed by one of the researchers in the first checkpoint after noticing that the stems of the involved plants were long but were unable to hold themselves upright. Palpably, the former was allowed to focus on growing light-harvesting organs and absorb more energy. Consequently, it had promoted the greatest overall mean height by the end of the experiment. However, both have allowed for a higher photosynthetic activity than white light (Sabzalian et. al, 2014).

There is no doubt that this study was conducted with its difficulties and limitations. As stated in the first chapter, both time constraints and the coronavirus pandemic have prompted the researchers to shelter the experimental setups within their own residences. The former has also contributed to only short-term experimentation being produced. Thus, while significant findings were observed during the twenty-day period, it is unknown whether those trends retained or would deviate further. However, the procured data is still variable because the situation of managing both a vertical garden and a small-scale conventional setup has remained properly replicated.

The researchers give the consent to future researchers to use this paper to research and experiment to verify and learn more information about LEDs and vertical farming. A recommendation for any similar future research would be to do a similar experiment but on a commercial scale and to do an economic study of this concept, as that is one of the limiting factors of the growth of vertical farming into the mainstream as of right now. As mentioned at the beginning of the paper, the researchers believe that vertical farming is not just a fad, but rather a necessary evolution of the farming sector to make it sustainable. It is not the one solution that we need. However, vertical farming available on a mass scale will be one of the steps that we as a species must take to ensure our sustainable growth on this planet.

CONCLUSIONS

Based on the significant findings noted during the experiment period and the subsequent data analysis, vertical farming methods were apparent to have yielded high values compared to conventional farming. Thus, similar to previous literature, the researchers have agreed that light-emitting diodes as a more advantageous farming method. To further discuss, the pink light group yielded the highest positive results, in both the mean height and numbers of leaves categories, among the four vertical farming setups, making it the most effective mode. Additionally, the same yielded data had proven a significant difference in terms of plant growth between the influence and absence of varying light sources. Consequently, the null hypothesis was rejected. While the experiment was considered to be a success, the researchers still recommend any further research to take note of different colors in the electromagnetic spectrum towards plants within a longer period of time.

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