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RESEARCH ARTICLE

EFFECTS OF DIFFERENT COLORS OF LIGHT ON THE GROWTH OF BELL PEPPER (*Capcicum annuum*)

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Abstract

This study was conducted to determine the agronomic characteristics of the effects of different colors and intensity of light on the growth of Bell Peppers *(Capsicum annuum).* This study used the experimental research method using a Complete Randomized Design (CRD). There are two factors in this experiment: Factor A, different colors (red, blue, and green), and Factor B, intensity of light (5W, 10W, and 15W). Agronomical characteristics were measured and statistically treated using Factorial Analysis of Variance to determine if different colors, intensities, and light interactions significantly affect the growth of Bell Pepper plants. The Tukeys procedure was used to determine which of the treatment means produced under varying light colors and intensities are significantly different from one another. The statistical significance of the parameter estimates was declared based on the Bonferroni adjusted level (α / k). Based on the analyses of the data gathered, the following conclusions were drawn: Among the light colors tested, red has the most significant effect on the growth characteristics of Bell Pepper. Among the intensities of the lights considered, 15W has the most significant effect on the growth characteristics of Bell Pepper. The combination of red color and 15W intensity has the most significant effect on the growth characteristics of Bell Peppers. As a result of this study, the researcher offers the following recommendations, believing they could improve/remedy the existing conditions. When plant is grown on artificial light, the researcher suggests that farmers use red light at 15W as a source of light aside from bright light, but not green light to prohibit plant growth in terms of height. In growing leafy vegetables, blue light at 15W is the best color and intensity of light to enhance leaf diameter. To produce dark green color of leaves, sunlight is still the best light-growing plant environment. In contrast, red light can be an alternative light during the rainy season. In achieving a greater number of leaves of plants, red light at 15 watts is the most advisable color and intensity of light. In choosing a plant material for the experiment, various plants must be considered to bear fruit. Exceed the number of hours of plant exposure to artificial light can be conducted aside from this study. Using other colors and high-intensity light is recommended for future researchers who want to conduct another study.

Keywords
Effects of lights
Color of lights
Intensity of lights
Bell pepper

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INTRODUCTION

Light is the source of energy for plant photosynthesis and growth. A wide range of signals and information for morphogenesis and many other physiological processes is triggered by light (Chen et al., 2004). Various light-related factors, including wavelengths, intensity, duration, and direction, can impact plant growth and development. Additionally, sensitive to all facets of illumination conditions is the process of photosynthesis. As sessile organisms, plants have evolved to respond to many environmental factors. Three environmental factors are essential to plants and will be used in this experiment. One of the most critical environmental factors for plants is light. Another one is radiation, which goes hand in hand with light. The third is the intensity of light, which is also related closely to the type of light given off. Plants use the energy from light for more than photosynthesis.

Nonetheless, photosynthesis is a sophisticated process that uses a variety of strategies to deal with photoinhibition. The primary preventive measure to eliminate the harm brought on by HL intensities is the dissipation of excess energy as heat (Müller et al. 2001). The term “non-photochemical quenching” (NPQ) of chlorophyll fluorescence refers to thermal dissipation. Non-photochemical quenching involves some techniques, such as energy-dependent quenching through the xanthophyll cycle, state transitions resulting from conformational changes in the light-harvesting complex II (LHCII), and photoinhibition that reduces quantum yield due to light-induced damage (Müller et al. 2001; Zhao et al. 2017).

Plant pigments take in and reflect light. Plants use chlorophyll A and B as their primary photosynthetic pigments. They mostly absorb the light spectrum’s blue and red wavelengths. All chlorophyll-based photosynthesis systems contain carotenoids with an absorbance spectrum ranging from 350 to 500 nm. They aid in the antenna system’s absorption of light. Carotenoids also aid the plant’s release of excess energy as heat to shield the photosynthetic mechanism from high light levels (Sharma and Hall 1993).

Furthermore, plants can react differently to light in different spectral bands. For example, the range of wavelengths required for electron excitation in the photosynthetic system is primarily present in red and blue lights (Taiz and Zeiger 2002). The effect of light is still one of the most complicated questions in plant study today. Not only do plants depend on light to help them determine what is in their surroundings, but they also depend on light to be able to photosynthesize and use that as their energy source (Berg, 2004). For a few years, more and more attention has been paid to the role of light intensity and its quality in terms of spectral composition on the growth of plants. People have limited knowledge of the role of light in plant growth. Due to their rapid growth, there has also been a surge in light-emitting diode (LED) lighting technologies in enclosed horticultural systems (Kozai et al., 2015).

The reactions involved in photosynthesis in plants are dependent on environmental conditions. Different light attributes, including spectrum and intensity, are considered to have the most direct effects on photosynthetic reactions (Chen et al., 2004). The parameter that will be focused on in this experiment is light spectral quality. This means which type of light, the color of the light, and the intensity that a particular light gives off. This experiment examined some of this light spectral quality and determined whether plants grew faster and healthier under different colors and intensities of light. This study aimed to determine the effects of different colors and light intensity on Bell Peppers’ growth. The light colors were selected based only on the availability of colors and the difference in bulb wattage available in the market. This study focused only on the different agronomic characteristics of plants in terms of agronomic characteristics; plant height, leaf diameter, color, and number of leaves. Only one type of plant, the Bell Pepper plant, was used in this experiment. The colors of light used were green, blue, and red. The different intensities of light used were 5 Watts, 10 Watts, and 15 Watts. The growth and physical appearance of the plant was observed. Some of the variables in this experiment were held constant to ensure equal effects of these variables on the plant growth and yield, such as soil mixture, dimension of box, water, temperature, size of polyethylene bag, and type and condition of seeds. No further chemical and biochemical tests were conducted. The researcher will use the ordinary ruler and meter stick to measure the height and leaf diameter of a Bell Pepper.

Research Questions

This study aimed to determine the physiological and biological effects of different colors and intensities of light on the growth of Bell Peppers *(Capsicum annuum).* Specifically, it sought to answer the following questions:

1. What are the observed effects of different colors and intensity of light on the growth of Bell Pepper in terms of the following agronomic characteristics:
    1.1. Plant height,
    1.2. Leaf diameter,
    1.3. Leaf color, and
    1.4. Number of leaves?
2. Is there a significant difference in the effect of different colors and intensity of light on the growth of Bell Pepper across the following agronomic characteristics:
    2.1. Plant height
    2.2. Leaf diameter; and
    2.3. Number of leaves?

METHODOLOGY

This study used the factorial experiment designed. The experiment was conducted in a dark room under laboratory conditions following the factorial in a completely randomized design (CRD). In a factorial design, main effects represent the individual impact of each factor on the dependent variable, while interactions signify the combined effect of two or more factors (Kirk, 2013). Furthermore, factorial designs are denoted as “a × b” designs, where “a” and “b” represent the number of levels of each factor. The design structure is depicted in a matrix, with cells representing unique combinations of factor levels (Kuehl, 2000). Understanding both main effects and interactions is essential for comprehensively interpreting experimental results. This experiment has two factors: Factor A, different colors of light (blue, red, green), and Factor B intensity of light (5W, 10W, 15W). Table 1 shows a Factorial Experiment Design (FED) in a Completely Randomized Design (CRD)—factor A, the three different colors, and Factor B, the three different wattages used. The dependent variables in this study were height, leaf diameter, and number of leaves.

Table 1. Factorial Experiment Design

		Factor A (Different Colors of light)		
		Blue	Red	Green
Factor B (Intensity of Light)	5W	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves
	10W	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves
	15W	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves	Height Leaf Diameter Number of Leaves

Table 2 shows a complete detail of other variables in the study that will remain constant. The Experimental group was exposed to artificial lighting, while the control group was exposed to natural light. The experimental and control groups will be replicated three times with five bell peppers per replication. The experimental group has three different intensity levels, while the control group relies only on natural light intensity. All the box's dimensions and the incandescent bulb's height were equally the same throughout the replication to ensure that each treatment received an equal level of photosynthetically active radiation (PAR). The experimental group will be separated into different boxes according to color and intensity (9 set-ups). On the other hand, the control group was placed outside in a mini greenhouse with one set-up. Duration of lighting and amount of water remain the same with the two groups.

Table 2. Other Variables in the Study

Group	Source of Light	Number of Replication	Intensity of Light	Dimension of Growing Place	Distance of light Bulb	Duration of Lighting	Amount of water
Experimental Group	Red, Blue, Green Incandescent bulb	3x per color & watts and 3x in sunlight	5W, 10W, 15W	61 cm width, 61 cm length and 122 cm height	100 cm	12 hours exposure (6:00 am to 6:00 pm)	50 mL (1^{st} 20 days) Then increase 50 mL every 10 days up to 60 days.
Control Group	Sunlight		Normal Light	180 cm width, 220 cm length and 230 cm height	100 cm from canopy to plants		

This experiment used the Yolo wonder variety of Bell pepper (*Capsicum annuum*) plant. One Bell pepper seed was sown in a 12 oz plastic cup with an equal depth of 3 cm, with an equal mass of soil mixture at about 250 grams—the Soil mixture comprised compost soil, animal manure, and rice husk. There were 150 sown seeds, which were grown under natural light conditions. Each plant received an equal amount of water at 50 mL every other day. When the second true leaf appeared, the plants were transplanted into a 7" diameter by 12" height polyethylene bag with a mass of soil mixture at about 1500 grams or 1.5 kilograms. The plants were transplanted with a depth of about 3". They were set up in a complete randomized design (CRD). There were n=9 (Bell pepper plants) in each lighting treatment. The plants were watered at 200 mL every other day at 6:00 in the morning. Standard pest and disease control measures were applied for all necessary experimental treatments. The plants in this study were divided into two groups: the control group (natural light) and the experimental group (blue, red, and green) in different light intensities (5W, 10W, 15W). There were three replications for each color and intensity of light as well as natural conditions.

The data collected were on plant height and leaf diameter, measured weekly every Saturday for six weeks. When taking measurements, the height of each plant from the soil level up to the tip of the plant was measured, and the diameter of each leaf that grew from each plant was likewise measured and randomly selected. The ruler and meter stick were used to determine the height and diameter of the plant leaf expressed in centimeters (cm). The height of the plants was measured to see which plants grew the quickest and tallest under the blue, red, green, and natural light of different intensities. The diameter of the leaves was measured to see which plant leaves grow the widest under the blue, red, green, and natural light of different intensities.

The plant's leaf color was also observed as dark green, green, light green, and yellow to see which plants absorbed more light under blue, red, green, and natural light in different intensities. The number of leaves of Bell Pepper was also counted, only the matured leaves were counted to find out which color and intensity of light is an effective light source. Agronomical characteristics such as plant height, diameter of leaf, the color of leaf, and the number of leaves were measured and statistically treated using Factorial Analysis of Variance to determine if different colors, intensities, and interactions of light significantly affect the growth of Bell Pepper plants. The Tukeys procedure was used to determine which of the treatment means produced under varying light colors and intensities are significantly different from one another. On the other hand, the orthogonal contrast procedure was used to determine the significant differences in the agronomic characteristics at different possible pairs of interactions of colors and intensities. The same orthogonal contrast procedure determined significant differences between means produced under natural and artificial light conditions. The statistical significance of the parameter estimates is declared based on the Bonferroni adjusted level (α / k).

This study's statistical calculations used STATA 8.0, an interactive data analysis program developed by Stata Corporation (Texas, USA) for data management, statistical analysis, and graphical works.

RESULTS AND DISCUSSION

Effects of Different Colors and Intensity of Light on the Growth of Bell Pepper

Table 3 presents the data gathered on the agronomic characteristics of Bell Peppers, such as height, leaf diameter, leaf color, and number of leaves. These characteristics were measured under two factors affecting growth: light color and intensity. In addition to the marginal effects of these factors, their interaction effects on the agronomic characteristics of Bell Pepper were also determined.

Table 3. Effects of Different Colors and Intensity of Light on the Agronomic Characteristics of Bell Pepper

Light Color	Intensity (Watts)			Mean
	5	10	15	
	Plant Height (cm)			
Red	26.33	32.00	48.00	**35.44**
Blue	20.67	34.00	36.33	**30.33**
Green	15.33	19.67	21.00	**18.67**
Natural	-	-	-	**43.33**
Mean	**20.78**	**28.56**	**35.11**	
	Leaf Diameter (cm)			
Red	3.67	3.87	3.83	**3.79**
Blue	3.60	4.57	4.87	**4.34**
Green	2.50	2.93	3.13	**2.86**
Natural	-	-	-	**4.33**
Mean	**3.26**	**3.79**	**3.94**	
	Number of leaves			
Red	22.00	28.00	58.00	**36.00**
Blue	8.33	35.67	35.00	**26.33**
Green	5.33	6.00	10.67	**7.33**
Natural	-	-	-	**41.33**
Mean	**11.89**	**23.22**	**34.56**	

Effect on Height

Color. Light is an essential factor in the survival of all living things. Compared to most animal forms, most plants need light to produce food as a raw material in photosynthesis. The color of the light can affect plants agronomical characteristics like height, leaf diameter, color of leaves and number of leaves depending on the color of the light utilized by plants because some light colors are absorbed and the plants reflect some. The quality of light influences the growth rate of plants. As supported by Riofrio, 2006, the growth rate is vital because a plant that achieves rapid growth and maturation in a short period will eventually first set its fruit. In this sense, there is more productivity for farmers and plant growers. This will address the high demands and ensure food security.

Three primary light colors such as green, blue, and red were considered, and their effects on the height of Bell Peppers were determined. As seen in Table 3, these three colors produced varying effects on the height of the Bell Pepper. Red produced the highest mean plant height (35.44 cm), while the lowest mean height was observed under green light conditions. Notice that the height of the plant under blue condition (30.33 cm) was between these two values, but the value is closer to red color. On the other hand, plants exposed to natural conditions can still be considered the best because their mean height was the highest compared to other plants grown under artificial lighting conditions.

Intensity. Other than the color, light intensity regarding Wattage rating was also considered**.** Several factors, like the temperature of the immediate surroundings and radiation, may change at varying light intensities. Due to increasing or decreasing light intensity, plants' growth rate may adjust. It can be deduced from the data gathered that light intensity could also produce varying effects on plant height, like light colors. As the table shows, the plants exposed to the highest intensity considered (15W) also obtained the highest mean height of 35.11 cm. On the other hand, the lowest mean height (20.78 cm) is equally observed in the lowest intensity tested (5W). The 10W intensity at the middle of the two intensities produced a mean height of 28.56 cm, which can be positioned in the middle of the two mean heights computed. Illustrating the observed values in Figure 1, one can observe that the Bell Pepper height seemed to increase at increased light intensity.

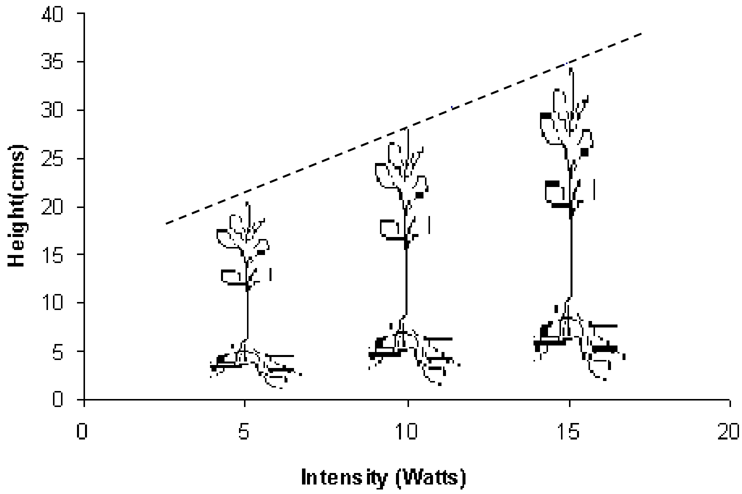

Figure 1. Pictorial Representation of the Mean Height of Bell Pepper at Increasing Light Intensity

Interaction. Color and light intensity may have separate effects on the agronomic characteristics of plants. However, these two factors can somewhat produce apparent effects if they interact. To visualize the effect of the interaction of light intensity and color on plant height, a mean line graph is constructed (Figure 2).

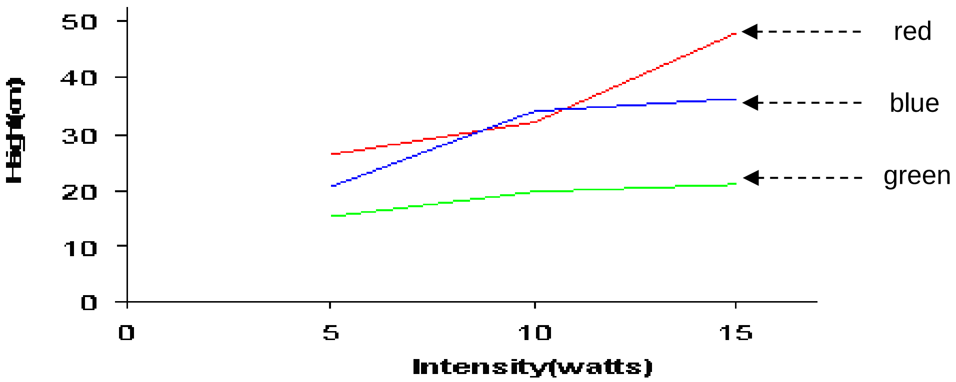

Figure 2. Mean Line Graph of the Effect of the Interaction of Colors and Light Intensity on the Height of Bell Pepper.

Although it can be seen in Figure 2 that all plants show an increasing trend with intensity, the observed rate of change seems to be different under each light color. As can be realized from the figure, the rate is higher for both red and blue light, where each attained the maximum mean height

(48 cm) at 15W. Although the rate is also increasing with light intensity for plants under green light conditions (21 cm), it is not as great as observed under the two colors. Further, it can be seen that the growth rate of the plants with intensity under blue light conditions seems to be steeper from 5W to 10W (20 to 34.00 cm) but slowed down from 10W to 15W (34 to 36.33 cm). These observations show that interaction between color and light intensities also plays a vital role in plant growth.

Effect on Leaf Diameter

Color. The color of the light is an exciting factor that brought about changes in the growth of different plants. Different light colors have a distinctive effect on the different parts of the plants, especially the leaves, because of their varying wavelengths. Tansley (2003) stressed that the leaf may be viewed as a solar collector crammed full of photosynthetic cells responsible for photosynthesis. Just like plant height, the size of the leaves is also essential. A plant with broader and longer leaves may collect light and produce food well. Hence, farmers who are planting leafy vegetables will benefit from this breakthrough. They can now harvest leafy vegetables with wider leaf diameters and probably high biomass and nutrient content.

As deduced in Table 1, these three colors produced varying effects on the leaf diameter of bell peppers. The blue light produced the highest mean leaf diameter (4.34 cm), while the lowest mean was observed under green light conditions. On the other hand, the leaf diameter of the plant under the red condition (3.79 cm) was ranked second, even though the plant in this condition had the highest mean height. However, the mean leaf diameter of the plant under natural conditions (4.33 cm) was rank second, but the mean is closer to blue condition.

Intensity. At different light intensities, several external factors, like temperature, may change, altering the growth of plants, either increasing or decreasing the growth. It can be connected from data gathered in Table 3 that intensity manifested change in the growth of Bell Peppers. The table shows that 15 watts produced the highest mean leaf diameter of 3.94 cm. Next is 10W, where a mean leaf diameter of 3.79 cm was produced. At the same time, the 5W bulb produces the lowest leaf diameter measurement with a mean leaf diameter of 3.26 cm. Although the mean effect produced by different light intensities is not too remarkably different, their effect is still visible.

Interaction. Different variables or factors have distinct effects on plant growth. Similar to height, color, and light intensity may have separate effects on the leaf size of bell peppers. A blend of these two factors could also produce an apparent effect. A mean line graph (Figure 3) is constructed to visualize the effect of the interaction of light intensity and color on plant leaf diameter. It can be noted in Figure 4 that the leaf diameter of the plant seems to increase with light intensity. Although all lines show an increasing trend, the rate of change is different under each light color and shows remarkable growth differences in leaf diameter.

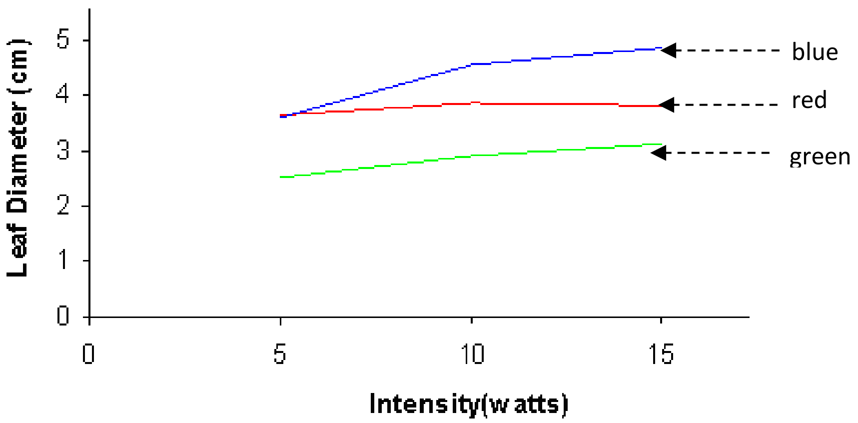

Figure 3. Mean Line Graph of the Effect of the Interaction of Colors and Light Intensity on the Leaf Diameter of Bell Pepper.

As can be realized from the figure, the rate is higher under the blue light where the observed maximum mean leaf diameter (4.87 cm) was attained at 15W. Although the rate is also increasing with light intensity for plants under green light conditions (3.13 cm), it is not as great as observed under the two colors. Further, it can be seen that the growth rate of the plants with intensity under red light conditions seems to be more comprehensive from 5W to 10W (3.67 to 3.87 cm) but slowed down and decreased from 10W to 15W (3.87 to 3.83 cm). From these observations, one can realize that interaction between immediate factors also plays an essential role in the growth of plants, especially in the leaf diameter of Bell Pepper.

It can be generally observed that in terms of leaf diameter, blue light produced the widest leaf diameter with a mean of 4.34 centimeters. One reason is perhaps because the wavelength at this color (440-490 nm) is minimal or low. Zalewska and Wozny (2005) explained that only the leaves were affected in growth, not the entire plant because not enough radiation was given off to prohibit the entire plant growth. Although red light produced the highest height measurement, it only ranked second in leaf diameter. Plants subjected to green light have a distinct smaller diameter of leaf and smaller length of height, possibly because plants do not absorb green light (Muller, 2001). This means farmers growing plants indoors can now think and have an effective and efficient lighting source for their plants—especially those farming using aquaponics and aeroponics indoors.

Effect on Leaf Color

Each plant has its natural leaf color. For a plant scientist, the color of the leaves can serve as a basis for diagnosing the plant with disease, nutrient deficiency, or toxicity. One can judge if a plant is healthy based on the color of its leaves. Environmental factors can affect leaf color. Table 4 shows the effect of different light colors and intensities on the color of the leaves of Bell Peppers.

Table 4. Color of Leaves of Bell Pepper at different Light Colors and Intensities

Color	**Intensity (Watts)**		
	5	**10**	**15**
Red	green	green	green
Blue	light green	light green	green
Green	yellow green	yellow green	yellow green
Natural	dark green	dark green	dark green

As seen in Table 2, these three colors and light intensity produced varying effects on the color of the leaves of Bell Peppers. Red light produced green leaf color regardless of the light intensity. The blue light produced light green leaves at 5W and 10W. However, a greener color was observed at the highest intensity (15W). On the other hand, green light produced yellow-green leaves at all intensities. On the other hand, plants grown under natural conditions produced the greenest (dark green) and the healthiest leaves so far. Regarding the degree of coloration, natural conditions produced the greenest dark green, followed by red light, then blue light, with green light producing the palest color. Except under green light conditions, the intensity of light seemed not to affect leaf color.

Effect on Number of Leaves

Color. The spectral quality of the light is an essential factor that influences changes in the growth of different plants. Different colors of light with varying wavelengths have a distinctive effect on the agronomical characteristics of plants. According to Riofrio (2006), a plant with more leaves seems to perform well in light collection and food production. Thus, plants with a greater number of leaves manufacturing more stems will ultimately produce more fruits. This will help farmers who are relying on the fruits of their plants. This may lead to better fruit production and address the issue of shortage of food in certain countries.

The three colors produced varying effects on the number of leaves of Bell Peppers (Table 1). Red produced the highest mean number of leaves (36.00), while the lowest mean was observed under green light conditions (7.33). On the other hand, the number of leaves of the plant under the blue condition (26.33) was in the middle, but the value is closer to red. However, the mean number of leaves of the plants under natural conditions (41.33) seems to appear superior to the three light colors.

Intensity. Other than the color of the light, the intensity in terms of Watts was also included. At varying light intensities, several external factors might adjust the growth of plants, either increasing or decreasing the growth due to varying light intensity. It could be noted from the data gathered (Table 4) that, like colors, light intensity also produced varying effects on some leaves. As seen in the table, the plants exposed to 15W obtained the highest mean number of leaves (34.56) and the lowest mean number of leaves (11.89) is also observed in the lowest intensity tested. The 10W intensity at the middle of the two intensities also produced a mean number of leaves of 23.22, which can also be positioned in the middle of the two mean numbers of leaves computed.

Interaction. To spot the effect of the interaction of light intensity and color on a number of leaves of the plant, a mean line graph is constructed (Figure 4).

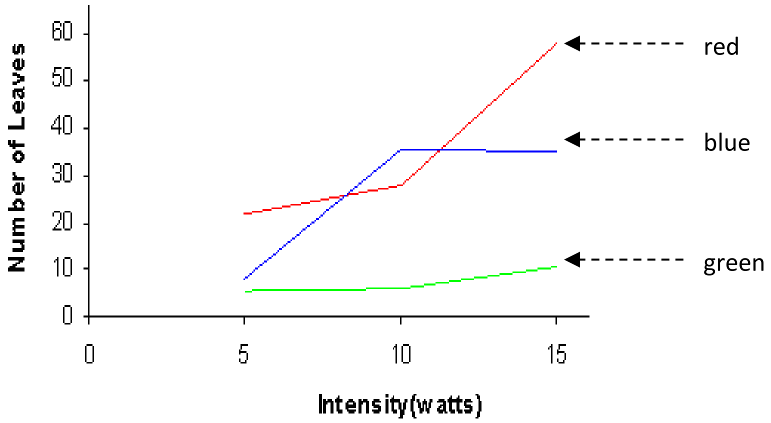

Figure 4. Mean Line Graph of the Effect of the Interaction of Colors and Light Intensity on the Number of Leaves of Bell Pepper.

As seen in Figure 4, the number of leaves of the plant seems to increase with light intensity. Although all lines show an increasing trend, the rate of change is different under each light color. As can be realized from the figure, the rate is higher under the red light, where the maximum mean number of leaves (58.00) was attained at 15W. Although the rate is also increasing with light intensity for plants under green light conditions (10.67), it is not as great as observed under the two colors. Further, it can be seen that the growth rate of the plants with intensity under blue light conditions seems to be steeper from 5W to 10W (8.33 to 35.67) but slowed down and decreased from 10W to 15W (35.67 to 35.00). Just like their effect on height and leaf diameter, one can realize that interaction between light colors and intensities could produce a marked effect on the number of leaves of Bell Peppers.

Comparison of the Effects of Different Colors and Intensity of Light on the Growth of Bell Pepper

Different combinations of light colors and intensities were tested, and their marginal and interaction effect were measured. Factorial ANOVA was used to test the significant differences in the effect of these factors on plant growth (Table 3).

Table 5. Summary of the Results of Factorial ANOVA.

Factors	Agronomic Characteristics					
	Height		Leaf Diameter		Number of Leaves	
	F	Sig	F	Sig	F	Sig
Light Color	276.48**	0.000	45.25**	0.000	276.40**	0.000
Light Intensity	192.48**	0.000	10.43**	0.001	166.91**	0.000
Color * Intensity	32.42**	0.000	2.17^{ns}	0.114	51.59**	0.000

**highly significant ^{ns}not significant

On the Height of Bell Pepper

Comparison Across Light Colors. It could be seen from the result of ANOVA in Table 3 that the color of light has a significant effect on the height of the Bell pepper. A multiple comparison using the Tukey procedure was performed to determine the significantly different treatment means (Table 4). It can be seen in the table that the highest difference in mean height was observed between red and green (16.78 cm), and the lowest was that between red and blue (5.11 cm). As can be realized from the table, all possible pairs are significant, an indication that the effect of all colors on plant height is significantly different. This supports the study of Taiz and Zeiger (2002) that different light colors possess different wavelengths; therefore, it significantly changes plant growth. This study will help farmers harvest their crops early due to the short period to grow them. It will enable them to plant more crops in every season.

Table 6. Multiple Comparisons of the Marginal Effect of Different Colors and Intensity of Light on Plant Height

	Compared Categories	Mean Difference	p-value/sig
Color			
	Red vs. blue	5.11*	0.000
	Red vs. green	16.78*	0.000
	Blue vs. green	11.67*	0.000
Intensity			
	5W vs 10W	7.78*	0.000
	5W vs 15W	14.33*	0.000
	10W vs 15W	6.56*	0.000

*significant at 5% level

Table 6 does not include the observations from the natural light condition because of the interaction effect of colors and intensities, which is lacking in this condition. An orthogonal contrast procedure was performed to compare the effect of natural conditions on plant growth with the different lighting colors. The result of the contrast procedure for the different agronomic characteristics is shown in Table 5. The height of bell peppers grown under blue and green light conditions significantly differs from the natural condition. On the other hand, no significant difference with natural conditions was seen for the Bell Pepper grown under red light conditions. As Muller et al. (2001) explained, natural and red light are rich in 600-700 nm wavelengths of energy. When compared, plants exposed to these wavelengths have no significant difference.

Across Light Intensities. It could be noted from the result of ANOVA (Table 3) that light intensity also significantly affects the height of Bell Pepper. A multiple comparison using Tukey's procedure was also performed to determine which treatment means differed significantly (Table 4). It can be seen in the table that the highest difference in mean height was observed between 5W and 15W (14.33 cm), and the lowest was between 10W and 15W (6.56 cm). As can be realized from the table, all possible pairs are significant, indicating that the effect of all intensities on plants is significantly different. An orthogonal contrast procedure was performed to compare the effect of natural conditions on plant growth of the different light intensities (Table 7).

The table shows that the heights of Bell Peppers grown under 5W and 10W light conditions significantly differ from the natural conditions. On the other hand, no significant difference with the natural condition was seen for the Bell Pepper grown under 15W condition. This is because plants under 15W light intensities are also comparable for the growth of plants.

Table 7. Orthogonal Contrast between Natural Light and the Different Colors and Intensities.

Categories	Height		Leaf Diameter		Number of Leaves	
	Diff	p-val/sig	Diff	p-val/sig	Diff	p-val/sig
Color						
Red	7.89^{ns}	0.105	0.54^{ns}	0.085	5.33^{ns}	0.524
Blue	13.00*	0.010	0.01^{ns}	0.971	15.00^{ns}	0.081
Green	24.67*	0.000	1.48*	0.000	34.00*	0.000
Intensity (Watts)						
5	22.56*	0.000	1.08ns	0.032	29.44*	0.005
10	14.78*	0.011	0.54^{ns}	0.263	18.11^{ns}	0.073
15	8.22^{ns}	0.138	0.39^{ns}	0.421	6.78^{ns}	0.491

*significant at Bonferroni adjusted level $(\alpha/3)$ ^{ns}not significant

Comparison Across Interactions. The interaction of light color and intensity significantly affects the height of Bell Pepper (Table 3). This is evident in the computed F-value of 32.42, corresponding to a p-value of 0.000. This indicates that color differences are not the same at different light intensities and that intensity responses differ among the light colors tested. An ordinary post hoc test could not solve a multiple comparison of the interaction effect, for these tests are for marginal effects only. Partitioning variances into the interactions or performing multiple contrasts could solve this problem (Table 8).

Table 8. Multiple Comparison of the Interaction Effect on Plant Height of Colors and Intensities of Light

Factors	Compared Categories	Mean Difference	p-value/sig
Light Color			
Red	5 vs 10	5.67*	0.000
	5 vs 15	21.67*	0.000
	10 vs 15	16.00*	0.000
Blue	5 vs 10	13.33*	0.000
	5 vs 15	15.67*	0.000
	10 vs 15	2.33^{ns}	0.082
Green	5 vs 10	4.33*	0.003
	5 vs 15	5.67*	0.000
	10 vs 15	1.33^{ns}	0.306
Light Intensities			
5 Watts	Red vs Blue	5.67*	0.000
	Red vs Green	11.00*	0.000
	Blue vs Green	5.33*	0.001
10 Watts	Red vs Blue	2.00^{ns}	0.132
	Red vs Green	12.33*	0.000
	Blue vs Green	14.33*	0.000
15 Watts	Red vs Blue	11.67*	0.000
	Red vs Green	27.00*	0.000
	Blue vs Green	15.33*	0.000

*significant ^{ns}not significant

In the multiple comparison procedure for interactions, each pair of light intensity was first tested for significant differences under each light color. It can be seen in Table 6 that for the plants exposed under green light color, the comparison is significant for all possible pairs. From this result, one can say that for the range of light intensity (5W to 15W), plant heights may not differ statistically if the light color is red. Under the blue and green light conditions, the 5W effect significantly differs from 10W and 15W. However, the effects of 10W and 15W are not significantly different. From this result, the light intensity did not significantly affect the height of the Bell Pepper at an intensity of 10W and higher when the plants were exposed to blue and green conditions.

The second part of the procedure compares the color effects under each light intensity. For the plants exposed under 5W and 15W light intensity, the comparison is significant for all possible pairs, as can be realized from the p-values of 0.000, 0.000, and 0.001 for 5W and 0.000 in all colors under 15W. Thus, one can say that for the three colors of light (red, blue, and green), the heights of the plant may not differ statistically if the intensity of the light were 5W and 15W.

Under 10W conditions, the red color of the light effect is significantly different from both blue and green conditions. However, the effect of red and blue was not significantly different. From this result, the light color did not significantly affect the height of Bell Pepper plants at a red and blue light color when exposed to 10W conditions.

On the Leaf Diameter of Bell Pepper

Comparison Across Light Colors. It can be noted from Table 3 that colors of light have a significant effect on the leaf diameter of Bell Peppers. A multiple comparison using Tukey's procedure was constructed to determine which treatment means significantly differ (Table 7).

Table 9. Multiple Comparison of the Marginal Effect of Different Light Colors and Intensities on Leaf Diameter

	Compared Categories	Mean Difference	p-value/sig
Color			
	Red vs. blue	0.55*	0.007
	Red vs. green	0.93*	0.000
	Blue vs. green	1.48*	0.000
Intensity			
	5W vs 10W	0.53*	0.009
	5W vs 15W	0.69*	0.001
	10W vs 15W	0.16^{ns}	0.596

*significant ^{ns}not significant

It can be seen in the table that the highest difference in mean leaf diameter was observed between blue and green (1.48 cm), and the lowest was that between red and blue (0.55 cm). As can be realized from the table, all possible pairs are significant based on p-values of 0.007, 0.000, and 0.000. This indicates that all colors' effects on plant leaf diameter differ significantly. For all the agronomic characteristics, the Factorial ANOVA does not include the observations from the natural light condition because of the interaction effect of colors and intensities (Table 5). The leaf diameter of bell peppers grown under green light conditions significantly differs from the natural condition. On the other hand, no significant difference with the natural condition was seen for Bell Peppers grown under red and blue conditions.

Comparison Across Light Intensities. Light intensity, like colors, also significantly affects the leaf diameter of Bell Peppers (Table 3). To ensure a difference in the plants' growth, multiple comparisons were also performed to determine which treatment means significantly differed from the other (Table 7). It can be seen in Table 7 that the highest difference in mean leaf diameter was observed between 5W and 15W (0.69 cm) and the lowest was between 5W and 10W (0.53 cm). On the other hand, a difference in mean leaf diameter (p-value of 0.596) was observed and found not significant between 10W and 15W.

An orthogonal contrast was performed to compare the effect of natural conditions on plant leaf diameter of the different light intensities (Table 7). The leaf diameter of bell peppers grown under 5W light conditions significantly differs from natural ones. On the other hand, no significant difference with the natural condition was seen for Bell Peppers grown under 10W and 15W conditions. At an increased intensity greater than 5W, the Bell Pepper's leaf diameter is the same as that of plants grown under natural conditions.

Comparison Across Interaction. It can be noticed in Table 5 that both factor effects (color and intensity) are significant if considered marginally. However, as seen in the table, the interaction of these factors has no significant effect on the leaf diameter of Bell Peppers. This is evident in the computed F-value of 2.17, considered insignificant at a 5% alpha level. This could lead one to believe that for any of the blend of color and intensity tested, no environmental impacts on the plants affected the plant's leaf diameter.

On the Number of Leaves of Bell Pepper

Comparison Across Light Colors. Colors of light have a significant effect on the number of leaves of Bell Peppers (Table 10). It can be seen in the table that the highest difference in mean number of leaves was observed between red and green (28.67), and the lowest was that between red and blue (9.67). As can be realized from the table, all possible pairs are significant, indicating that the effect of the different colors on the plant's number of leaves is remarkably different.

Table 10. Multiple Comparison of the Marginal Effect of Different Light Colors and Intensities on Plant Number of Leaves

	Compared Categories	Mean Difference	p-value/sig
Color			
	Red vs. Blue	9.67*	0.000
	Red vs. Green	28.67*	0.000
	Blue vs. Green	19.00*	0.000
Intensity			
	5W vs 10W	11.33*	0.000
	5W vs 15W	22.67*	0.000
	10W vs 15W	11.33*	0.000

*significant at 5% level

An orthogonal contrasts procedure was performed to compare the effect of natural conditions on the number of leaves of Bell Peppers with the effect of the different lighting colors (Table 5). The number of leaves of Bell Peppers grown under red light conditions significantly differs from the natural conditions. However, no significant difference with the natural condition was seen for Bell Peppers grown under red and blue conditions. As discussed before, the closeness of the empirical values for red and blue conditions could attest to this insignificant difference.

Comparison Across Light Intensities. Light intensity also significantly affects the number of leaves of Bell Peppers (Table 3). Another run of Tukey's procedure was performed to determine which treatments differ significantly (Table 8). The highest difference in the mean number of leaves was observed between 5W and 15W (22.67), and the lower mean differences were observed for the remaining pairs of light intensities. Notably, the results appear to be significantly different. For the orthogonal comparison with the natural condition with the result in Table 5, bell peppers grown under the 5W condition significantly differ from the natural condition. On the other hand, just like the effect on leaf diameter, no significant difference with the natural condition was seen for plants grown under 10W and 15W conditions in terms of the number of leaves.

Comparison Across Interaction. The color and intensity of light interaction significantly affect the number of leaves of Bell Peppers (Table 7). This is evident in the computed F-value of 51.59, which yielded a significant value of 0.000. This indicates that color differences are not the same at different light intensities and that intensity responses differ among the light colors tested. Multiple comparisons of the interaction effect for Factorial ANOVA could be solved by performing multiple contrasts (Table 11).

Table 11. Multiple Comparison of the Effect of Light Intensities on Number of Leaves under Different Light Colors

Light Color	**Compared Categories**	**Mean Difference**	**p-value/sig**
Red	5 vs 10	13.67*	0.000
	5 vs 15	16.67*	0.000
	10 vs 15	3.00^{ns}	0.180
Blue	5 vs 10	7.67*	0.000
	5 vs 15	22.00*	0.000
	10 vs 15	29.67*	0.000
Green	5 vs 10	23.00*	0.000
	5 vs 15	47.33*	0.000
	10 vs 15	24.33*	0.000
Light Intensities			
5 Watts	Red vs Blue	6.00*	0.012
	Red vs Green	36.00*	0.000
	Blue vs Green	30.00*	0.000
10 Watts	Red vs Blue	27.33*	0.000
	Red vs Green	26.67*	0.000
	Blue vs Green	0.67^{ns}	0.760
15 Watts	Red vs Blue	0.67^{ns}	0.760
	Red vs Green	5.33^{ns}	0.023
	Blue vs Green	4.67^{ns}	0.043

*significant at Bonferroni adjusted level (5%/3) ^{ns}not significant at Bonferroni adjusted level (5%/3)

Similar to the multiple tests conducted for the interaction effect on the mean height of bell peppers, a parallel procedure was implemented for the number of leaves. Each pair of light intensities underwent an initial examination for significant differences under each light color. Notably, the comparison was significant for all possible pairs under both blue and green light conditions. This implies that within the range of light intensities (5W to 15W), the number of leaves did not exhibit significant differences when Bell Peppers were exposed to blue and green light. Under red light conditions, the effect of 5W differed significantly from both 10W and 15W. In contrast, the effects of 10W and 15W were not significant, suggesting that light intensity did not significantly impact the number of leaves at 10W and 15W under red light conditions. Additionally, comparisons of color effects under each light intensity were made. At 5W, all color pairs were statistically significant, indicating no difference in the number of leaves for the tested colors. Under 10W, green light significantly differed from red and blue light, while no significant difference was observed between blue and green light. Finally, at 15W, no significant differences were found among the number of leaves for all color pairs, as indicated by computed p-values of 0.760, 0.023, and 0.043. This implies that, under 15W conditions, the number of leaves for plants exposed to different colors did not differ significantly.

CONCLUSION AND RECOMMENDATION

The study highlights that red light, among the tested colors, and an intensity of 15W exert the most substantial influence on the growth characteristics of Bell Pepper. The combined effect of red color and 15W intensity is particularly noteworthy. The following recommendations are proposed to optimize plant growth conditions and guide future research endeavors. Farmers are encouraged to integrate red and bright light in artificial light settings, steering clear of green light due to its inhibitory effect on plant height growth. The study suggests using blue light at 15W to cultivate leafy vegetables to enhance leaf diameter. While sunlight remains optimal for achieving dark green leaves, red light can be a viable alternative during the rainy season. To promote a greater number of leaves, red light at 15W is advised.

In selecting plant varieties for experimentation, choosing materials suited to the local climate is imperative, ensuring optimal growth and fruit production. Additionally, exploring extended exposure hours beyond those studied here could yield valuable insights into the effects of prolonged artificial light exposure on plant growth. Furthermore, future researchers are encouraged to explore alternative colors and higher light intensities to expand our understanding of their impacts on plant growth. Lastly, to comprehensively investigate plant growth, it is recommended that additional factors such as temperature, soil type, pot size, and fertilizer application be integrated and controlled in future studies. These recommendations aim to refine agricultural practices and contribute to the ongoing advancement of knowledge in the science of plant growth.

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