Journal of Educational Technology and Learning Creativity
Vol. 3, No. 1, June 2025, pp. 27~38
ISSN: 3021-7865, DOI: 10.37251/jetlc.v3i1.1617

The Effect of LED Light Intensity on the Growth of Spinach (*Amaranthus* sp.): A Comparative Study of Green and Red Varieties

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Article Info

Article history:

Received Mar 2, 2025
Revised Apr 11, 2025
Accepted May 1, 2025
Online First May 2, 2025

Keywords:

LED Light
Light Intensity
Spinach Growth
Urban Farming

ABSTRACT

Purpose of the study: This study aims to examine the effect of LED light power on the growth of spinach plants (*Amaranthus sp*.) and compare the impact of different LED power levels on the growth of green and red spinach.

Methodology: This study used white LED lights (3W, 5W, 6.5W), a lux meter, thermometer, ruler, and camera. Green and red spinach seeds were planted in polybags with a soil and fertilizer mixture. An experimental method was applied with weekly growth measurements. Data were analyzed using descriptive statistical calculations.

Main Findings: The results show that 3W LED light provides the best growth for green and red spinach, with greater leaf width, leaf count, and stem height compared to 5W, 6.5W, and no light. Excess light (6.5W) hinders growth, while no light causes pale and wilted leaves. Red spinach grows faster than green spinach.

Novelty/Originality of this study: This study reveals that 3W LED light is more effective in promoting spinach growth than higher wattages or no additional light. These findings provide new insights into optimal light power selection for plant growth, benefiting urban farming, hydroponics, and indoor cultivation.

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1. INTRODUCTION

Sunlight is the main source of energy for the life of all living things in the world, one of which is plants. For plants, especially those with chlorophyll, sunlight determines the process of photosynthesis [1]-[3]. Photosynthesis is a basic process in plants to produce their food. Where in this process the energy of sunlight is needed for the unification of CO_2 and water to form carbohydrates [4]-[6]. Solar radiation captured by chlorophyll in plants that have green leaves is energy in the process of photosynthesis [7]-[9]. The results of this photosynthesis are the main ingredients in the growth and production of food crops [10]-[12]. In addition to increasing the rate of photosynthesis, increased sunlight usually accelerates flowering and fruiting.

Conversely, a decrease in the intensity of solar radiation will extend the growth period of plants. The effect of light elements on plants is focused on vegetative and generative growth. Plant responses to light are determined by the synthesis of green leaves, stomatal activity (respiration, transpiration), anthocyanin formation, temperature of surface organs, absorption of mineral nutrients, permeability, respiration rate and protoplasm flow [13]-[15]. Lack of sunlight will interfere with the process of photosynthesis and growth, although the need for light depends on the type of plant [16]-[18]. In addition, lack of light during development will cause etiolation

symptoms, where the sprout stems will grow faster but weak and the leaves are small, thin and pale in color (not green).

These etiolation symptoms are caused by lack of light or the plant is in a dark place. Light also acts as an inhibitor in the growth process, this happens because it can stimulate the diffusion of auxin to parts that are not exposed to light [19]-[21]. The light that acts as an inhibitor is caused by the absence of light so that it can maximize the function of auxin to support plant cells, conversely, plants that grow in bright places cause plants to grow fresher and the sprout stems are stronger [22]-[24]. Vegetables are commodities that have very high development, because they are needed in everyday life and their demand tends to continue to increase [25]-[27]. Just like other horticultural plants, most vegetable plants have a fairly high commercial value.

This fact can be understood because vegetables are always consumed at all times. In addition, vegetables are a plant commodity that is very much needed by the community because they contain many nutrients needed by the body. Spinach is one type of commercial vegetable that is easily obtained in every market, both traditional markets and supermarkets [28]-[30]. The price is affordable for all levels of society [31], [32]. This spinach plant originally came from tropical America, but is now spread throughout the world [31]-[34]. In Indonesia, only two types of cultivated spinach are known, namely pulled spinach (Amaranthus tricolor L.) and picked spinach (Amaranthus hybridus L.). This type is deliberately cultivated for consumption because the leaves taste good, are soft and have high nutritional content.

In addition, the fresh leaves have high commercial value. Spinach is widely promoted as a leaf vegetable source of nutrition for people in developing countries. Domestically, nutritional needs are increasing day by day in accordance with the increase in population, increasing age, better living standards and awareness of the importance of nutrition in daily food [31]-[33]. This causes an increase in demand for horticultural products, especially spinach plants. Pulled spinach is a spinach that is widely cultivated by farmers. Spinach is easy to grow and produces quickly. Spinach is suitable for planting in almost every type of soil and can grow all year round at altitudes up to 1000 meters above sea level, in less than a month the spinach can be harvested.

Thailand, as a tropical country in Southeast Asia, has climatic conditions and agricultural patterns similar to Indonesia, making spinach a commonly cultivated crop in both traditional and modern farming systems [38], [39]. In Thailand, spinach is grown not only for local consumption but also to support small-scale household farming and urban agriculture, which are increasingly promoted as sustainable food sources in urban and peri-urban areas [40], [41]. The demand for leafy vegetables, including spinach, continues to rise in Thailand due to growing health awareness and the expansion of health oriented diets [42], [43]. However, challenges related to inconsistent sunlight exposure especially during the rainy season or in shaded urban areas—have led researchers in Thailand to explore alternative lighting technologies, such as LED lamps, to support plant growth in controlled environments.

Initially, the lamps used as a source of room lighting were incandescent lamps and fluorescent lamps. However, over time, the function of LEDs has increased. One of them is to grow plants, so this LED lamp is also called a plant lamp because it does not cause heat that can damage plants. The highest photosynthesis occurs at noon, namely from 11 am to 2 pm and will decrease sharply if covered by clouds, at 6 pm to 6 am it does not occur because there is no sunlight. Therefore, artificial lighting is needed from electric lamps that can be turned on continuously so that the photosynthesis process is not disturbed. LED lamps are the first lamps tested for hydroponics because they have a wavelength that is suitable for the photosynthesis process of plants. This lamp is able to increase the plant growth process so that it provides more optimal production. LED lamps are safer to use because they do not use a glass layer, do not produce high temperatures, and do not contain mercury.

Based on a review of previous studies, such as those by Martínez-Moreno et al. [44] and Gao et al. [45], it appears that most research has focused on the effects of light intensity and LED spectrum on the growth of spinach in general, particularly in hydroponic systems. These studies primarily emphasize the influence of red and blue light spectra or the R:B ratio, as well as nutritional content aspects, without specifically addressing the impact of different LED power levels (in watts) on spinach growth, especially in soil-based cultivation. Moreover, most of the existing research does not explicitly compare the growth responses of green and red spinach varieties under varying LED power levels. This gap indicates the need for further research that specifically investigates the effects of different white LED power levels (3W, 5W, and 6.5W) on the growth of both green and red spinach varieties using conventional soil media. Therefore, this study is important in providing more practical insights into the use of artificial lighting in simple or household farming environments and contributes to the development of energy-efficient and appropriate plant cultivation strategies.

LED plant growing lamps are very suitable for increasing the production of vegetables and fruits. From morning to evening, plants will rely on sunlight for their photosynthesis process, and in the afternoon to evening they can get light from LED lights. As the photosynthesis process gets longer, plants will be more economically productive. However, in order to grow healthily, plants should be exposed to sunlight or LED lights with a total exposure of no more than 14-16 hours per day. The selection of lamp power for plants is also very important.

Large lamp power will emit high heat or light and can affect plant growth. Plants that get too much light will result in little chlorophyll and low photosynthesis results, the same thing happens if the plants lack light. Treatment with 15 watts of light tends to be slower, compared to pandan plants that are given treatment in a dark room. However, pandan plants that are given artificial light from artificial lamps (incandescent lamps) grow normally and pandan plants that are given treatment in a dark place grow abnormally, this is indicated by yellowish leaves and plants that look wilted and not sturdy. The aim of this study was to determine the effect of LED light power (Watts) on the growth of spinach (*Amaranthus sp*.) and to compare the effects of providing LED light power (Watts) on the growth of green spinach and red spinach..

2. RESEARCH METHOD

The tools and materials used in this study consisted of various instruments and materials to support observations of spinach plant growth. The tools used included a thermometer to measure environmental temperature, a luxmeter to measure the intensity of light received by the plant, a ruler to measure plant height, and a camera to document changes in spinach plant growth. Meanwhile, the materials used in this study included green spinach and red spinach seeds as the main subjects of the study, plastic (polybags) as planting containers, LED lights with different power (3 watts, 5 watts, and 6.5 watts) as additional lighting sources, planting media in the form of soil, and water for watering and maintaining plant humidity.

The work procedure in this study consisted of several main stages, namely luminescence testing, planting procedures, and data collection. At the luminescence testing stage, the lamp to be used was installed by hanging it, then the luxmeter measuring instrument was placed directly under the lamp that had been installed and supplied with electricity. After the lamp was turned on, its position was adjusted until the desired light intensity was obtained, then observations were made on the light intensity using a luxmeter.

The planting stage began with preparing green spinach and red spinach seeds. Next, the planting medium is prepared by mixing soil and manure in a ratio of 1:2, then put into a polybag. Spinach seeds are sown in polybags, then watered with water to maintain plant moisture. After that, the spinach plants in polybags are placed in an area with sufficient light intensity and given lighting from white LED lights with different powers. Additional lighting is provided when the sun begins to set, which is around 19.00 to 22.00 Central Indonesian time. In the data collection stage, the growth of green spinach and red spinach plants is observed every week by measuring variables such as leaf width, number of leaves, and stem height. The results of the observations are recorded in a table for further analysis. The flowchart of this research is as follows:

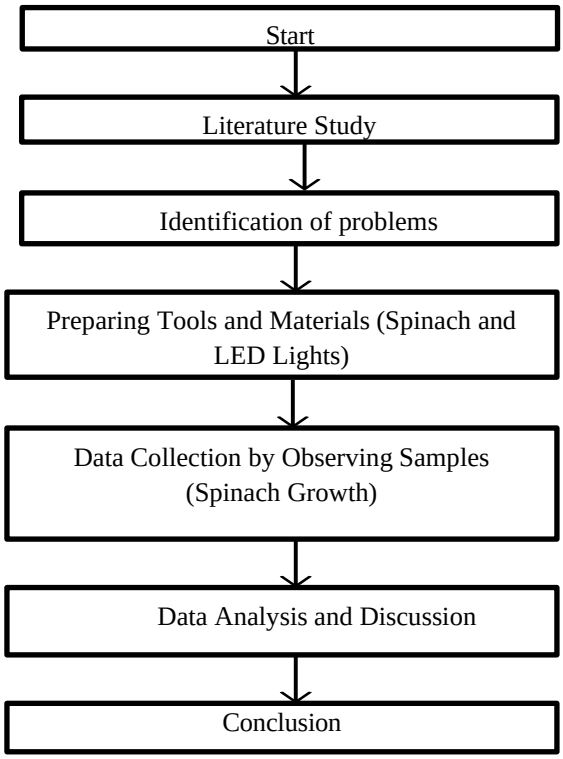


Figure 1. Research Flow Chart

3. RESULTS AND DISCUSSION

Spinach cultivation has been studied in various ways to obtain abundant harvests. This study was carried out by adding white LED lighting with different power for 3 hours at night in an open space with a lamp power of 6.5 watts, 5 watts, 3 watts and plants without lights with a light intensity of around 270 lux or with a lamp distance of around 38-59 cm from the plant. The time for irradiating the plants was when the sun began to set around 19.00-22.00 Central Indonesian Time. The variables measured in this study included leaf width, number of leaves and stem height which were measured every week with a temperature ranging from 22-25° C. Temperature measurements were also carried out to control the environmental temperature around the plants. In each data collection, 4 measurements were taken to obtain maximum results. Measurements were taken every 7 days (every week) around 15.00 Central Indonesian Time and ended in the fourth week with a stem height of 23-28 cm. The seeds used in this study were green bayan amarin and red spinach, the plants were watered in the morning by watering the plants with water ranging from 100-500 ml. The soil used was compost soil and organic fertilizer used from chicken manure, by mixing the soil and organic fertilizer, namely 1:2. Spinach plants were planted in polybags measuring 17.5x40 cm by randomly sowing the seeds in the polybags.

3.1. The Effect of Light Power on the Growth of Leaf Width, Number of Leaves and Stem Height of Green Spinach and Red Spinach Plants

The results of the research and calculation of the average figures, obtained from repeated data collection on the growth measurements of green spinach plants that have been carried out for 4 weeks, can be seen in table 1 below:

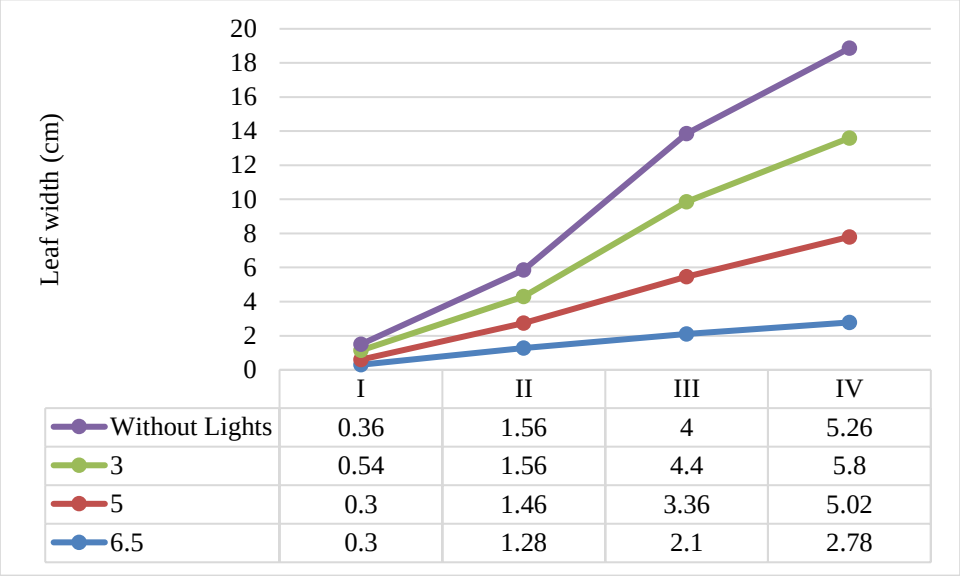
Table 1. Results of measuring the growth of green spinach plants every week.

Week To	Temperature (°C)	Lamp Power (Watt)	Leaf Width (cm)	Number of Leaves	Stem Height (cm)
I	22	6.5	0.3	2	0.7
II	23		1.28	4	2.1
III	25		2.1	6	3.8
IV	24		2.78	8	5.5
I	22	5	0.3	3	0.62
II	23		1.46	4	2.2
III	25		3.36	7	5.6
IV	24		5.02	10	9.2
I	22	3	0.54	3	0.7
II	23		1.56	5	3
III	25		4.4	10	11
IV	24		5.8	14	18.7
I	22	Tanpa Lampu	0.36	3	1.4
II	23		1.56	5	2.12
III	25		4	8	8
IV	24		5.26	10	14.8

The image obtained from the results of the research on the growth of green spinach plants that was carried out for 4 weeks can be seen in the following image 2:

Figure 2. Green Spinach Plant

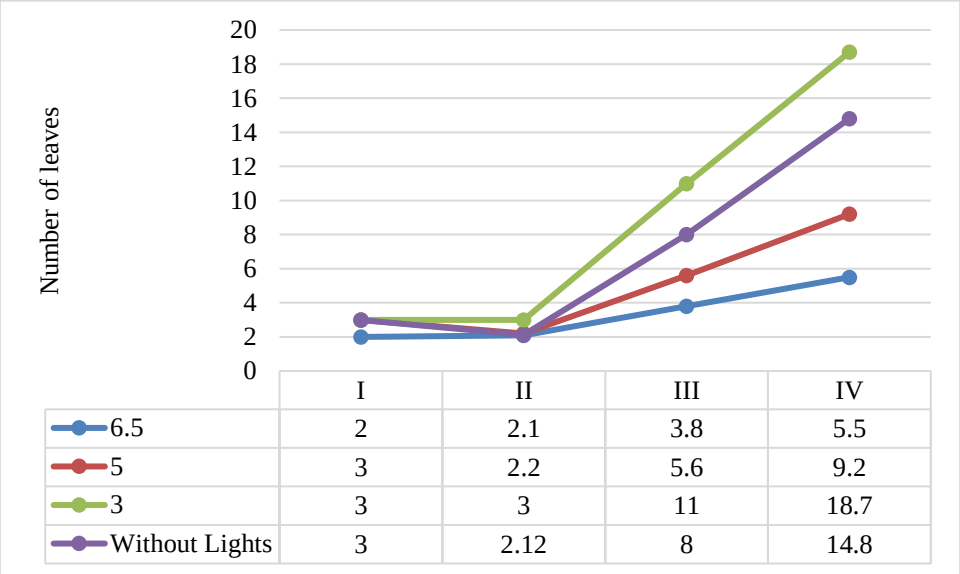
Based on the results of measurements with several measurement variables with 3 types of light power and without lights used on the growth of the green spinach plants produced, this can be seen in the following graph:



	I	II	III	IV
Without Lights	0.36	1.56	4	5.26
3	0.54	1.56	4.4	5.8
5	0.3	1.46	3.36	5.02
6.5	0.3	1.28	2.1	2.78

Figure 3. Graph of the effect of light power on the width of the leaves of green spinach plant growth.

Based on the graph above, it can be seen that the leaf width obtained on each stem has a different leaf width, from the 4 samples used, namely plants that use light with different powers and plants without lights, the largest leaf width growth can be seen, namely plants that use 3 watt light, while the slowest plants in leaf width growth are plants that use 6.5 watt light. Furthermore, the effect of light power on the leaf width of green spinach plant growth is presented in Figure 4.



	I	II	III	IV
6.5	2	2.1	3.8	5.5
5	3	2.2	5.6	9.2
3	3	3	11	18.7
Without Lights	3	2.12	8	14.8

Figure 4. Effect of light power on the number of leaves in green spinach plant growth.

Based on the graph obtained, it can be seen that the growth of the number of leaves from each stem varies, from 4 samples the fastest leaf growth is still the same as the growth of the width of the leaves, namely spinach plants that use 3 watt light with 14 leaves and 10 leaves for 5 watts and those without lights and 8 leaves for 6.5 watt lights. In addition, the leaves produced also look fresher than the leaves of plants that do not use lights.

Furthermore, the graph of the effect of light power on the height of the stem of the growth of green spinach plants every week is presented in Figure 5:

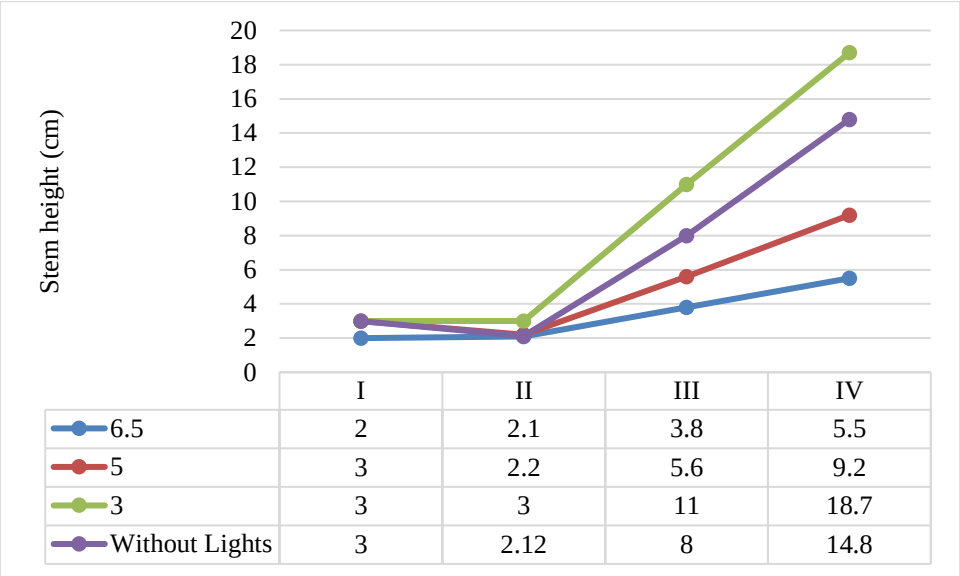


Figure 5. Graph of the effect of light power on the height of the stem growth of green spinach plants every week

The height of the stem also obtained the same results as the results of the growth of leaf width and number of leaves, namely, plants with 3 watts of light grow faster than plants with 5 watts and 6.5 watts of light or plants without lights, this is because planting using the intensity of light that has been set affects plant growth.

So it can be said that the growth of green spinach given 3 watts of light affects the width of the leaves, the number of leaves and the height of the stem. This is because plants that get too much light will result in little chlorophyll and the results of photosynthesis will be low, the same thing also happens if the plants lack light. The addition of light that greatly affects the growth of green spinach plants in terms of increased production and in terms of leaves produced fresher and wider leaf size, namely plants given 3 watts of light.

The results of the research and calculation of the average numbers, obtained from repeated data collection on the measurement of the growth of red spinach plants that have been carried out for 4 weeks can be seen in table 2 below:

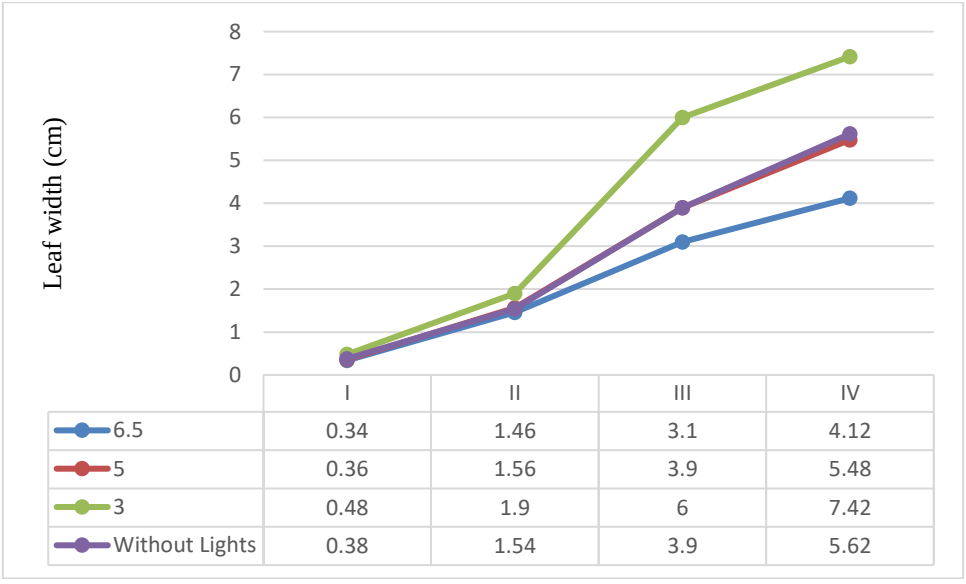
Table 2. Results of measuring the growth of red spinach plants every week

Week To	Temperature (°C)	Lamp Power (Watt)	Leaf Width (cm)	Number of Leaves	Stem Height (cm)
I	22	6.5	0.34	2	0.44
II	23		1.46	4	2.2
III	25		3.1	6	4.2
IV	24		4.12	8	5.6
I	22	5	0.36	3	0.78
II	23		1.56	5	3
III	25		3.9	6	6.4
IV	24		5.48	9	9.5
I	22	3	0.48	3	0.88
II	23		1.9	5	2.9
III	25		6	8	12
IV	24		7.42	13	20.9
I	22	Without Lights	0.38	2	0.76
II	23		1.54	4	1.8
III	25		3.9	7	7.4
IV	24		5.62	8	11.6

The image obtained from the results of the research on the growth of red spinach plants that was carried out for 4 weeks can be seen in the following image 6:

Figure 6. Red spinach plant

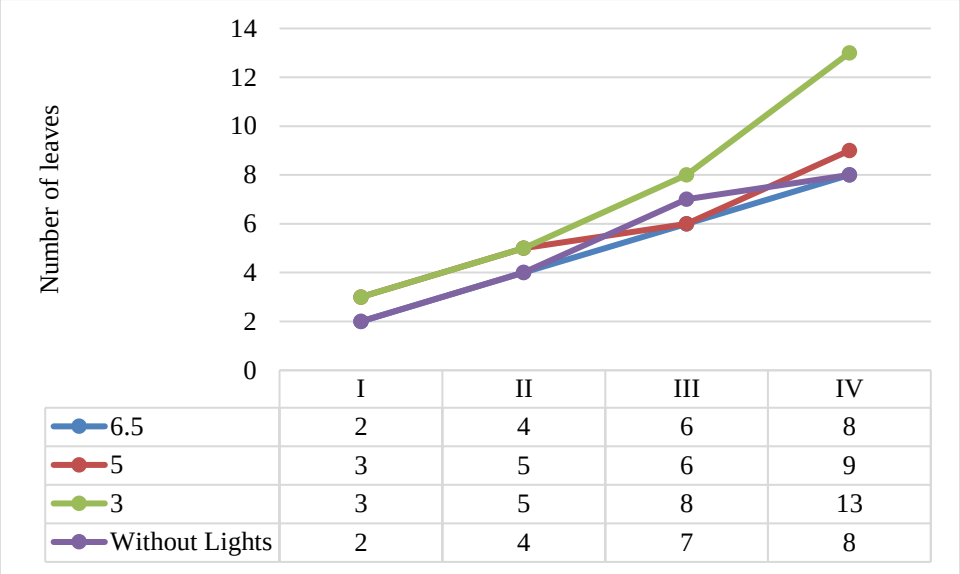
Based on the results of measurements with several measurement variables with 3 types of light power and without lights used on the growth of red spinach plants produced can be seen in the following graph.:



	I	II	III	IV
6.5	0.34	1.46	3.1	4.12
5	0.36	1.56	3.9	5.48
3	0.48	1.9	6	7.42
Without Lights	0.38	1.54	3.9	5.62

Figure 6. Effect of light power on leaf width of red spinach plant growth

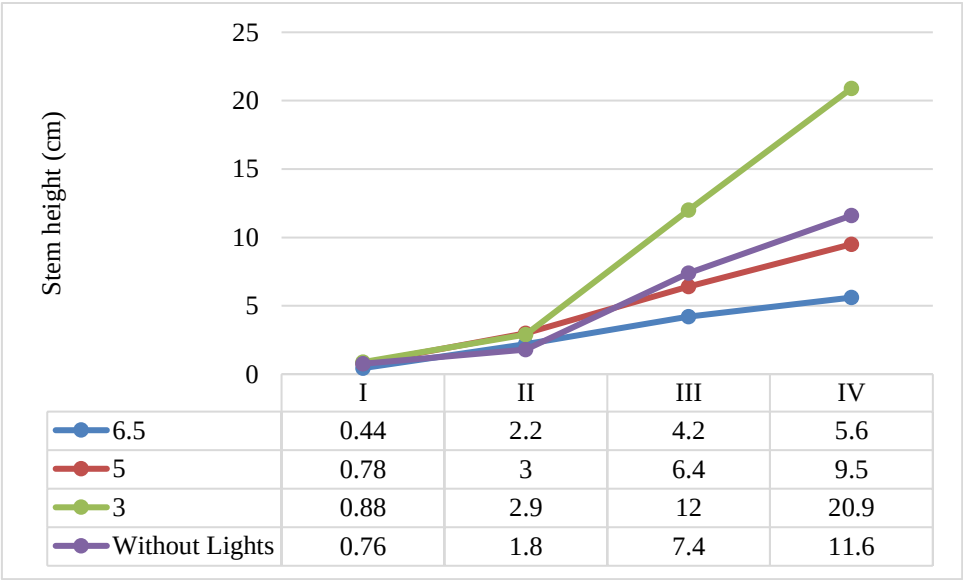
Similar to green spinach, plants using 3 watt lamps have faster leaf width growth, which is 7.42 cm compared to 5 watt, 6.5 watt and no lamp light, but not much difference between the leaf width of 5 watt lamp light, which is 5.48 cm and the leaf width without lamp, which is 5.62 cm. And the 6.5 watt lamp light has the slowest leaf width growth, this is because excessive light will result in little chlorophyll and low photosynthesis results. Furthermore, the graph of the effect of lamp power on the number of leaves of red spinach plant growth each week is presented in Figure 7:



	I	II	III	IV
6.5	2	4	6	8
5	3	5	6	9
3	3	5	8	13
Without Lights	2	4	7	8

Figure 7. Effect of light power on the number of leaves in red spinach plant growth

For the number of leaves produced by plants using 3 watt light, the number of leaves is greater compared to 5 watt and 6.5 watt light and without light, the same as green spinach plants. It can be seen that the effect of adding light plays a role in the photosynthesis process where plants without light have slow leaf growth in the growth of red spinach plants. This is as explained in the theory that large light power will emit high heat or light which can affect plant growth, where plants that get too much light will result in little chlorophyll and low photosynthesis results. The same thing also happens if the plants lack light. Next, a graph of the effect of light power on the height of the stem of red spinach plant growth is presented every week.



	I	II	III	IV
6.5	0.44	2.2	4.2	5.6
5	0.78	3	6.4	9.5
3	0.88	2.9	12	20.9
Without Lights	0.76	1.8	7.4	11.6

Figure 8. Graph of the effect of light power on the height of the red spinach plant growth stem each week.

The height of the stem also obtained the same results as the results of the growth of green spinach plants both in terms of leaf width and number of leaves, namely, plants with 3 watt light grow faster than plants with 5 watt and 6.5 watt light or plants without lights. It can be seen the difference with a large range between 3 watt lights with 5 watt light and without lights, this is because planting using the light intensity that has been set affects plant growth. Based on the results of the study, it can be seen that the effect of providing additional white light with different light power at night gives better results because the leaves produced are brighter and fresher due to the photosynthesis reaction, as is known that this photosynthesis reaction occurs in chlorophyll so that it greatly affects the green leaves of plants. Compared to plants without lights can cause the color of the leaves to appear

pale and wilted. From the research that has been done, the data inputted in the graph above is the data obtained every week by taking data 5 times or 5 spinach plants at each light power and averaged. Changes in plant development look different or slow when using 5 watt and 6.5 watt lamp power for both green spinach and red spinach. So it can be concluded that the recommended addition of light is the provision of 3 watt lamp light because it does not cause heat that can damage plants and its growth is fast. And plants without lights cause the color of the leaves to appear pale and wilted.

As explained in the theory, according to (Mukhlis, 2011) states that the selection of lamp power for plants is also very important. Large lamp power will emit high heat or light and can affect plant growth. Plants that get too much light will result in little chlorophyll and low photosynthesis results, the same thing happens if plants lack light. The highest photosynthesis occurs at noon, namely from 11 am to 2 pm and will decrease sharply if covered by clouds, at 6 pm to 6 am it does not even take place because there is no sunlight. Therefore, artificial lighting is needed from electric lamps that can be turned on continuously so that the photosynthesis process is not disturbed.

Addition of light using LED lights to plants is done at night or in the afternoon to increase the duration of the photosynthesis process in plants so that plants will be more economically productive, because LED lights are also called plant lights because they do not cause heat that can damage plants. However, in order to grow healthily, plants should be exposed to sunlight or LED lights with a total exposure of no more than 14-16 hours each day, this is because the plants do not turn pale or wilt. The use of inappropriate lights and too long can affect plant growth.

3.2. Comparison of the Effect of Light Power on the Growth of Green Spinach and Red Spinach Plants

The results of the research and calculation of the average figures, obtained from repeated data collection on the growth measurements of green spinach and red spinach which have been carried out for 4 weeks can be seen in table 3 below:

Table 3. Comparison of the effect of light power on the growth of green spinach and red spinach plants

Observation	Green Spinach				Red Spinach			
	Without Lights	3 watt	5 watt	6.5 watt	Without Lights	3 watt	5 watt	6.5 watt
Leaf Width (cm)	5.3	5.8	5	2.8	5.6	7.4	5.5	4.1
Number of Leaves	10	14	10	8	8	13	9	8
Stem Height (cm)	14.8	18.7	9.2	5.5	11.6	20.9	9.5	5.6
Average Temperature	24° C							

Based on the table above, it can be seen that the growth of green spinach and red spinach in the fourth week experienced changes in terms of leaf width growth, number of leaves, and plant stem height. The growth of this plant is influenced by several factors including the intensity of light used and other factors such as rainfall, full sunlight, temperature and soil moisture.

From the data obtained, it can be seen that the growth of red spinach has a faster harvest time compared to green spinach plants. The growth of red spinach plants in the fourth week of 3 watt light has reached 20 cm while in green spinach plants it has only reached around 18 cm. This comparison of spinach heights that is not too far apart can be caused by several other external factors, and so is the case for plants without lights. Plants that use 5 watt light on green spinach and red spinach grow almost the same, as do plants that use 6.5 watt light on green spinach and red spinach.

Plants that use 3 watt light based on research that has been done experience the best growth in terms of leaf width compared to 5 watt and 6.5 watt light and plants without lights, where the effect of additional light from 3 watt lights on leaf width reaches 5.8 cm in green spinach and 7.4 cm in red spinach. While in plants without lights the leaf width only reaches 5.3 cm in green spinach and 5.6 cm in red spinach. The leaves produced are also fresher and brighter in plants that use light compared to plants without lights.

Similarly, with the height of the stem and width of the leaves, plants that use 3 watt light have more leaves, namely 14 sheets in green spinach and 13 sheets in red spinach, and plants without lights in green spinach the growth of the number of leaves is the same as 5 watt light while in red spinach the growth of the number of leaves without lights is the same as 6.5 watt light, this is because plants that get too much light will result in little chlorophyll and low photosynthesis results, the same thing also happens if the plant lacks light.

The results of this study are supported by the results of previous research conducted by Martínez-Moreno et al. [44], related to evaluating the effects of various LED light intensities and spectra on spinach growth in a vertical farming system. The results showed that higher light intensity increased the fresh weight, dry weight, and

leaf area of spinach. However, increasing light intensity can also increase energy consumption, so it is necessary to consider energy efficiency in practical applications. Then, a study by Nguyen et al.,[46], observed the effects of light intensity from a combination of red and blue LEDs on the growth, photosynthesis, and microstructure of hydroponic spinach leaves. The results showed that appropriate light intensity can increase the growth and photosynthesis efficiency of spinach, as well as positively affect leaf structure. Furthermore, research by Lőrinc et al., [47] investigated how light intensity and spectrum composition affect spinach growth and metabolism. It was found that optimal light intensity can improve spinach growth and quality, while certain light spectrums can affect the accumulation of important metabolites in plants.

The above studies support the findings of the current study that optimal LED light intensity can improve spinach growth, including leaf width, leaf number, and stem height. However, it is important to consider that too high light intensity can cause stress to plants and increase energy consumption. Therefore, selecting the right light intensity is crucial to achieve optimal and energy-efficient plant growth. This study provides novelty by specifically investigating the effects of various LED light intensities on spinach plant growth in a relevant local context, using growth parameters such as leaf number, leaf width, and stem height.

Unlike previous studies that generally focus on large-scale indoor farming systems or aspects of plant metabolism, this study provides a practical approach to utilizing LED light intensity as an easily modifiable variable to efficiently increase plant productivity. The results showed that a light intensity of 21,000 lux gave the best results for spinach growth, which can be a reference for urban farmers and hydroponic farmers in managing lighting for maximum results. The implications of this study can be applied in the development of modern agricultural systems that are energy efficient, environmentally friendly, and sustainable, especially in urban areas that have limited land and natural lighting.

This study has several limitations, including the relatively short observation duration, which was only four weeks, so it has not been able to describe the long-term impact of light treatment on the overall spinach life cycle. Recommendations for further research are to conduct observations over a longer period of time and use a closed planting room or greenhouse to obtain better environmental control. It is also recommended to add other variables such as the type of LED light color, irradiation frequency, and leaf nutrient content analysis so that the research results are more comprehensive and applicable to various plant cultivation scenarios.

4. CONCLUSION

Based on the research that has been conducted, it can be concluded that the addition of 3 watts of light to plants has a significant effect on plant growth, such as the width of leaves and the number of leaves of green spinach and red spinach which are greater compared to 5 watts, 6.5 watts, and without lights, and the height of the stem which grows faster in 3 watts. Conversely, plants given 6.5 watts of light experienced slow growth and plants without lights showed pale and wilted leaves. In addition, a comparison between the growth of green spinach and red spinach showed that red spinach had a faster harvest time than green spinach. Plants given low-power light showed better growth compared to those given high-power lights or without lights, because high light power can produce excess heat which inhibits growth and reduces chlorophyll, while lack of light can also reduce photosynthesis results. Recommendations for further research are to conduct observations over a longer period of time and use a closed planting room or greenhouse to obtain better environmental control. It is also recommended to add other variables such as the type of LED light color, irradiation frequency, and leaf nutrient content analysis so that the research results are more comprehensive and applicable to various plant cultivation scenarios.

ACKNOWLEDGEMENTS

We express our gratitude to the presence of God Almighty for His grace and blessings so that this research can be completed properly. We would like to thank all parties who have provided support, guidance, and assistance during the research process. Hopefully this research can provide benefits for the development of science and be a useful reference for future research.

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