Original Research Article

Impact of Light Wavelengths on Photosynthetic Rates in Plants

Abstract

In this study, we investigated the effects of different light wavelengths, specifically red, blue, and green light, on the rate of photosynthesis in plants. Transmittance rates were collected at three-minute intervals over a nine-minute duration, and the photosynthetic rates were calculated for each wavelength. Our findings revealed that the red light wavelength resulted in a higher rate of photosynthesis (2.14%) compared to blue (1.57%) and green light (1.81%). Interestingly, the control group, which represented white light, exhibited the highest rate of photosynthesis at 2.31%. These results suggest that red light is more effective in promoting photosynthesis than blue or green light, and white light may be even more efficient. This information is crucial for understanding optimal growth conditions for plants, particularly in controlled environments such as indoor farms, where light wavelengths can be manipulated to maximize growth rates and crop yields. Further research should focus on comparing the effects of red, white, and other light wavelengths on photosynthesis to determine the most effective wavelength for plant growth and to explore potential synergistic effects of different light combinations.

Keywords: photosynthesis, light wavelengths, red light, indoor farming, plant growth

I. Introduction

Photosynthesis is the process which traps solar energy [1]. Organisms unable to take in energy for themselves require photosynthesis [1, 2]. Most of the energy on Earth cycles through photosynthesis, as it is the first stage of the food chain. [3] Without photosynthesis, life on Earth would not be possible. In the process of photosynthesis, energy is captured by pigments such as chlorophyll a, from light in the thylakoid membrane of a plant cell's chloroplast, where light reactions take place [1, 4]. Afterwards, carbohydrate formation in the stroma via the Calvin Cycle, (the outside of the chloroplast), proceeds to create glucose, energy that is of use to the plant cell. In cellular respiration, the conversion of glucose to ATP is the process in which plant cells are able to utilize this energy [1, 4].

The equation for photosynthesis is $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$, including light over the yield sign, which drives the reaction [5, 6]. Both the reactants and products are of equal value, given matter cannot be created nor destroyed. In photosynthesis, light fosters the oxidation of water molecules and reduction of carbon dioxide, which results in glucose and oxygen as by-products. In this experiment we analyzed the effects of light in the process of light reactions and photosynthesis [5, 6].

Light reactions are the light dependent portions of photosynthesis. Light dependent reactions require the absorption of light, where ATP and NADPH are created as byproducts to power the Calvin Cycle, where glucose is synthesized. ATP and NADPH are the products of light reactions in the thylakoid, which are essential to driving the process of photosynthesis [7]. In our experiment we analyzed the reduction of blue light in DPIP to understand the changes in the rate of photosynthesis in spinach leaves.

In this experiment we replaced the light reactions electron carrier, $NADP^+$ with DPIP, a blue 2,6-di-chlorophenol-idophenol. The DPIP reduced to DPIPH, a clear liquid, which was analyzed in the spectrophotometer for light transmittance to measure light transmission quantitatively, as DPIP changed from blue to colorless.

Color theory depicts that all colors visible to the naked eye reflect that specific color, reflecting all others [8]. Because spinach is the color green, and red light is the opposite of green light in color theory, the wavelengths of red light will have higher rates of photosynthesis than green light [8, 9].

In this experiment we tested how the color of light, or wavelength, affects the rate of transmittance, or photosynthesis, in a plant cell, specifically: a spinach leaf. The independent variable was the wavelength of light chosen, while the dependent variable, the photosynthetic rate (change in %T over time recorded). Our hypothesis was developed on the premises of color theory, given red and green are on opposite spectrum, we made the observation that red light, opposing green, is strongest absorbed by the color green, the color of a spinach leaf.

II. Materials and Methods

Spinach leaves were used in this experiment for the acquisition of chloroplasts. The spinach leaves were initially taken out of the refrigerator and de-vined to remove large pieces of the spinach that had little to no chloroplasts. The chloroplasts were placed underneath a lamp to prime them for photosynthesis. After being primed, the chloroplasts were placed into a chilled blender, cold to preserve the chloroplasts and prevent the rate of photosynthesis from dropping before the experiment. Mixed with 0.5mL of sucrose solution to maintain an isotonic environment, the blender mixed the chloroplasts in three 10 second bursts, to prevent the buildup of heat, in order not to overstimulate, and thus preserve the chloroplasts. The chloroplasts were emptied into a three-layer cheesecloth to sift out large pieces of spinach, and preserve a concentrated solution of chloroplasts.

Transferring the chloroplasts to our lab, we held all materials: DPIP, chloroplasts, distilled water, and the phosphate buffer, in a cooler to preserve the chloroplasts. In a tube rack there were five tubes, of which would be a calibration tube to set the %T to 100% before each testing session, and three chloroplast tubes, a control, a tube under green light, a tube under red light and a tube under blue light. At this time, the spectrophotometer was turned on in order to warm up and prepare for readings. Each tube was filled with a 1mL phosphate buffer to maintain the pH level. In the calibration tube 4mL of water and 1mL of chloroplast were added. In each of the other tubes, 1mL of phosphate buffer, 3mL of water, and 1mL of DPIP was added. DPIP was added to replace $NADP^+$ to observe the changes in transmittance. Each tube was then put into the cooler to preserve the chloroplasts until it was time to start the experiment.

After each tube was filled, tubes 1, 2, 3, and 4 (red, blue, green, white/control) were ready to be tested for 0 minutes. We set the spectrophotometer to 605 nm, though before putting any tube into the spectrophotometer, we would invert the tube with parafilm on top, to prevent contents from spilling, then wipe off the tube with a kim-wipe, to ensure no fingerprints or liquids were on the tube, since this could interfere with the photospectrometry readings for the rate of transmittance. The test tubes were inverted to make sure the contents are diluted and mixed well, so that chloroplasts are evenly throughout the solution. The calibration tube, which had no DPIP, was set in at 0 minutes to set the transmittance rate (%T) to 100%, meaning all light was transmitted through, and then each tube was quickly taken out of the cooler, where they had been stored and placed into the spectrophotometer, where the data was read, the tube was taken out, and then placed into a rack under lamp light for photosynthesis, this process was repeated for all four tubes. Under the goose-neck lamps, each tube, red, blue, green, and white had the same environment, in which a Erlenmeyer flask sat a heat sink to prevent the chloroplasts from overheating, across from the tube rack, which a single tube sat and absorbed the energy.

In this experiment our independent variable is a change in wavelength. The control for this experiment was white light. White light displays photosynthesis without the manipulation of wavelength. We expected to see photosynthesis occur under white light, establishing a baseline of what "normal" rates of photosynthesis read as.

We calculate the rate of photosynthesis by taking the change in transmittance rate over the change in time. Rate = (Change in %T)/(Change in time). We calculate the rate of photosynthesis to determine how much light is moving through the chloroplasts, and thus, how much the chloroplast photosynthesis. In this experiment the more that a chloroplast synthesizes, the greater the rate of photosynthesis will be, because the more photosynthesis that occurs, the more DPIP will turn from blue to colorless, and result in greater levels of light being transferred through the tube in the spectrophotometer.

III. Results

We collected the transmittance rate of each tube at three-minute intervals, starting at minute 0. The initial readings were 18.70%, 18.90%, 19.00%, and 16.20% for the red, blue, green, and control tubes, respectively (Data Set 1). The control showed a significant increase in photosynthetic rate by the 3-minute mark, with a 10.10% increase, while the red, blue, and green wavelengths increased light transmittance by 6.00%, 5.60%, and 4.90%, respectively (Graph 1, Data Set 1).

At the 6-minute mark, the transmittance rates for the control and each variable were approximately 30%, indicating a continued increase in photosynthesis rates (Graph 1). The red wavelength increased by 6.30%, while the blue and green wavelengths increased by 3.70% and 5.10%, respectively. The control experienced a 5.20% increase (Data Set 1).

By the 9-minute mark, the peak transmittance rate was observed for the red wavelength at 38.30%, while the lowest rate was observed for the blue wavelength at 33.00%. The green wavelength and the control recorded transmittance rates of 35.30% and 37.00%, respectively (Data Set 1).

To determine the rate of photosynthesis over the nine-minute duration for each wavelength, we employed the equation (Change in %T)/(Change in Time). The resulting rates were 2.14%, 1.57%, 1.81%, and 2.31% for the red, blue, green wavelengths, and the control, respectively (Data Set 2).

These findings demonstrate the varying effects of different light wavelengths on the rate of photosynthesis, with red light showing a notably higher rate compared to blue and green light. Furthermore, our data suggest that white light, as represented by the control, may have a more significant impact on the rate of photosynthesis than previously expected. This information is crucial in understanding the optimal conditions for plant growth, particularly in controlled environments such as indoor farms, where light wavelengths can be manipulated to maximize growth rates and crop yields.

IV. Discussion

In our study, we aimed to investigate the rate of photosynthesis in response to different light wavelengths, specifically red and green light. Our findings revealed that the photosynthetic rate under red light was significantly higher than that under green light, corroborating our initial hypothesis. This observation is consistent with the understanding that different light colors have distinct absorption rates, which in turn influence the photosynthetic rate [10].

The green chloroplasts in our experiment were expected to have a higher photosynthetic rate under red light, as plants primarily absorb red and blue light due to the presence of chlorophyll a and b [11]. Our data imply that, in the presence of green or red light, autotrophic organisms utilizing chloroplasts will exhibit optimal photosynthetic performance under red light. Surprisingly, the highest photosynthetic rate was observed under the control condition, suggesting that white light may be more effective than red light or that there were potential errors in our experimental setup.

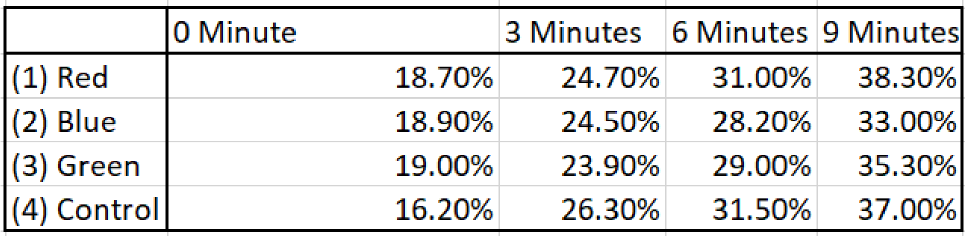
Potential limitations in our study could have influenced the results. For instance, factors such as fingerprints, water, or small smudges on the tubes may have affected the transmittance rates. Additionally, the red light bulb may have been less potent than the green and control bulbs, requiring replacement. Future experiments should consider the use of more robust controls and equipment to minimize potential confounding factors.

Our findings have practical implications in agriculture, particularly for optimizing plant growth in indoor farming settings [12]. Our data suggest that green light should be avoided in favor of red light, while white light may be the most effective for promoting photosynthesis. This information can help increase plant growth rates in controlled environments by manipulating light wavelengths, ultimately improving crop yields and food production efficiency.

Further research should focus on comparing the effects of red, white, and other light wavelengths, such as blue light, on photosynthesis to determine the most effective wavelength for plant growth [13]. A deeper understanding of how different light wavelengths impact photosynthetic rates is essential for optimizing agricultural practices and promoting sustainable food production. Additionally, investigating the potential synergistic effects of different light wavelengths in combination may reveal new insights into plant physiology and adaptation mechanisms.

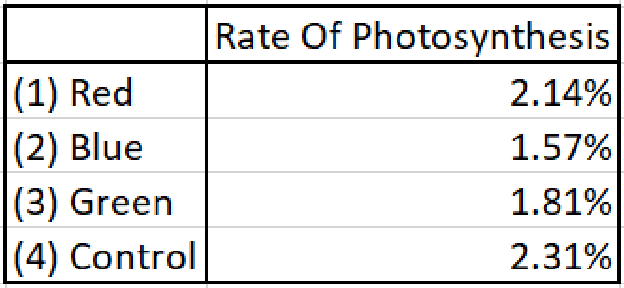
Appendix

Data Set 1, Light Transmittance over 9 minutes



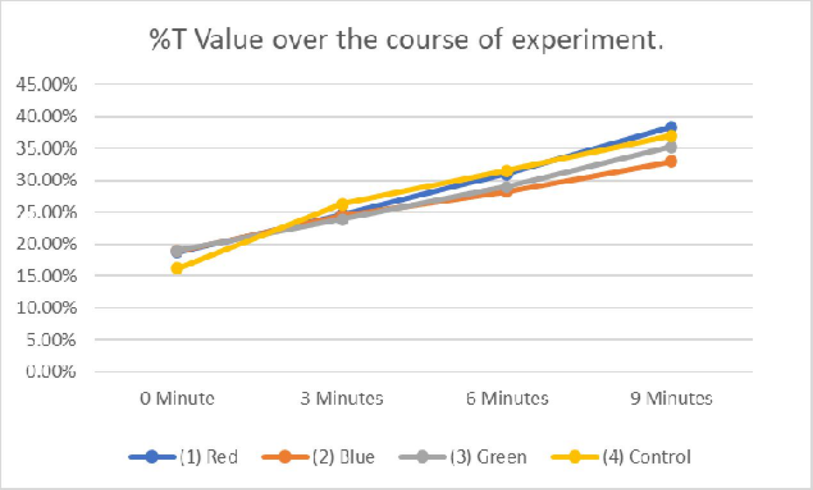
	0 Minute	3 Minutes	6 Minutes	9 Minutes
(1) Red	18.70%	24.70%	31.00%	38.30%
(2) Blue	18.90%	24.50%	28.20%	33.00%
(3) Green	19.00%	23.90%	29.00%	35.30%
(4) Control	16.20%	26.30%	31.50%	37.00%

Data Set 2, Rate of Photosynthesis over 9 minutes



	Rate Of Photosynthesis
(1) Red	2.14%
(2) Blue	1.57%
(3) Green	1.81%
(4) Control	2.31%

Graph 1



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