Colors And Plant Growth In Baby Spinach Leaves

Abstract

The effect of light wavelength on the rate of photosynthesis in baby spinach leaves was determined by recording the consumption of carbon dioxide for four minutes. Red, blue, and green light were tested to determine which color increased the rate of photosynthesis the most. Each color has a specific range of wavelengths to describe it, and the closer the wavelength is to the accepted, the more carbon dioxide was consumed. The graphs supported the prediction that as the wavelength of light changed, the rate of photosynthesis also changed. The ideal wavelength was found to be around 492 to 577 nm (corresponding to green light); however, more tests could be done to determine the ideal absorption range. If the accepted wavelength of individual plants could be found, larger amounts of nutritious foods could be produced decreasing malnourishment rates and feeding a growing population.

Introduction

Photosynthesis has two main functions— convert light energy into chemical energy and convert inorganic carbon to organic carbon. The created chemical energy is in the form of carbohydrates that can be converted into adenosine triphosphate (ATP) through cellular respiration. Photosynthesis is the reverse reaction of cellular respiration; the products of cellular respiration can be used as reactants for photosynthesis and vice versa. If there is no light present, plants can undergo cellular respiration to gain the energy they need; however, they will generate no biomass. Photosynthesis has two steps: the light-dependent and the light-independent reactions. During the light-dependent reactions, photons break water bonds, creating atmospheric oxygen and hydrogen ions in the thylakoid. Light energy, water, and carbon dioxide are converted into chemical energy in the form of ATP and NADPH. The light-independent reactions consist of cyclic reactions that occur in the stroma. The chemical energy from the light-dependent reactions is combined with rubisco and carbon dioxide to form simple sugars. Even though the light-independent reactions do not need direct light to occur, neither step could happen in the absence of light as the Calvin cycle requires intermediates produced during light-dependent reactions. Photosynthesis results in biomass through carbon fixation, allowing all life on Earth. Organisms that cannot produce chemical energy for themselves can gain the nutrients they need by consuming plants or other species that consume plants. Additionally, photosynthesis produces oxygen, which is essential for many species (Angilletta 2018).

As plants can only absorb a certain range of wavelengths, the hypothesis that different colored lights will affect the rate of photosynthesis was tested. Depending on the range of wavelengths the plant accepts, some colors will improve while others will inhibit plant growth. The more similar the color's wavelength is to the acceptable range; the faster photosynthesis will occur. If the wavelength is dissimilar to the accepted range, photosynthesis will slow or stop altogether. The ideal range was unknown prior to the lab and was determined experimentally. To determine how different wavelengths affect photosynthesis, carbon dioxide concentrations were tested with a Pasco® carbon dioxide sensor for the red light, blue light, green light, and control trials. As the negative slope becomes steeper, the rate of photosynthesis increases.

If colored light does affect photosynthesis, and therefore plant growth, the knowledge can be utilized in a multitude of ways. Certain wavelengths of light could be used to either raise or destroy crop yield. The ideal wavelength could be determined experimentally in a similar way to discover what factors lead to higher, more nutritious crop yield. Sofia Carvalho and Kevin Folta discuss the possible benefits of using specific wavelengths to improve plant growth. Within their introduction, they state “variation in light quantity, quality, duration or combinations can be used to change plant growth, development or metabolism to influence a desired final product” (Carvalho and Folta 2014). Throughout the article, the key findings of researchers’ studies on a multitude of specific plants were summarized. For example, the growth of lettuce was tested under “blue, red, and a combination of red and far-red light sources… to adjust lettuce leaf size and shape, taste, color texture, and nutrient content when compared to white light” (Carvalho and Folta 2014). Multiple researchers found that “blue light exposure promotes growth, leaf area and biomass increase… while red-rich sources stimulate leaf elongation and lower growth rates” (Carvalho and Folta 2014). If a specific color were found to improve crop yields, more food, or more nutritious food, could be harvested with lower energy costs. Beth Johnson, Consuelo De Moraes, and Mark Mescher investigated the effects of light spectroscopy on parasites to determine ways of killing harmful plants without killing the crop. When exposed to far-red light, the plant’s growth was not affected. However, the “host location and subsequent attachment by dodder parasites was dramatically reduced in high-R:FR environments” (De Moraes et al. 2016). By determining how light affects different organisms, crop yields could be increased to feed a growing population while parasitic plants could be killed with no harm to the host. Additionally, more nutritious plants could be grown through light technology, which could solve the global malnourishment epidemic.

Methods

To test the effects of wavelength on photosynthesis, two leaves were subjected to different colored lights. The concentration of carbon dioxide was recorded every ten seconds to determine the rate of photosynthesis. If photosynthesis occurred, the correlated graph would have a negative slope because carbon dioxide is consumed during the process. The steeper the graph’s slope, the faster the rate of photosynthesis. In summary, the independent variable was the color of light while the dependent variable was the amount of carbon dioxide present over four minutes. As leaves must be alive to undergo photosynthesis, the negative control tested the rate of fake leaves. As many plants can grow under artificial white light, the positive control tested the rate of photosynthesis under a white CFL bulb. Even though a better positive control would have been natural sunlight, it would have been difficult to test the rate of carbon dioxide consumed outside, and other variables would have been affected. If the positive control was done outside, all the other tests would also have had to be done outside. Not only that, the amount of light the plant could consume throughout the experiment would change as the sun set. To ensure that no other factors contributed to the results, there were many controlled variables. The same sized leaves were used each time to ensure that the mass, the species, and the rate of each leaf was nearly constant throughout. Each trial was done within the laboratory to assure that the outside environment did not change individual samples. To adequately compare the rates of photosynthesis, each trial was tested for four minutes with the concentration of carbon dioxide recorded every ten seconds. Additionally, the same wattage was used for each colored light bulb to avoid the effects of light intensity. To control the wavelengths entering the container, aluminum foil was placed around the container and the lamp to trap the light in a relatively closed system. Even though the same leaves and sensor were supposed to be used for every trial, these two factors had to be changed throughout the experiment due to uncontrollable errors.

Before the effect of colored light on photosynthesis could be tested, the system was calibrated to set a baseline reading of carbon dioxide. To calibrate the Pasco® carbon dioxide sensor, the calibration button was pressed until the green light blinked. To ensure that the sensor adequately calibrated, all group members stepped away from the table until the light stopped blinking. SPARKvue was set up to record carbon dioxide concentration every ten seconds for four minutes. Two leaves were randomly chosen from the same sample and were placed in a clean container smooth side up. The sensor was attached with no openings present, and the container was then placed on its side which allowed more light in. To test the negative control, fake leaves were placed inside the container because they were not alive. After the negative trial was done, the graph was scaled to determine if photosynthesis took place and saved to the computer. To test the positive control, the two spinach leaves were added to a clean container with the sensor attached. A lamp was placed over the container, and a white CFL bulb was turned on. Additionally, aluminum foil was placed around the container and lamp to trap the light inside. Once the positive trial was done, the graph was scaled to determine if photosynthesis took place. The raw data of both controls were saved to the computer to be analyzed later.

Once the controls were done and saved, the effects of different wavelengths were tested. For the colored light bulbs, multiple trials of each were done with two similar leaves for four minutes each. To test red light, two leaves were placed in the container with the carbon dioxide sensor placed on top and the lamp overhead. After the three trials of red were done, the graphs were scaled, and the raw data was saved to the computer. The red light bulb was replaced with the blue light bulb in the lamp. Once the four trials of the blue light were done, the graphs and data were saved. The green bulb replaced the blue one for the last two trials. Similarly, the graphs were scaled, and the data was saved for further analysis. As the trials occurred, the raw data was analyzed to determine if the plants were truly undergoing photosynthesis. After all the trials were done, the lab station was cleaned and organized.

Discussion

Because individual plant chloroplasts can only absorb a certain range of the electromagnetic spectrum, the hypothesis that different colored lights affect the rate of photosynthesis was tested. Depending on the ideal wavelength range of baby spinach, the closest wavelength range should change the rate of carbon dioxide consumption. The hypothesis was somewhat supported by the collected data. The white, blue, and green lights had different rates of carbon dioxide consumption with green light being the most effective (wavelength of 492-577 nm). The negative control should have had no increase nor decrease in carbon dioxide, yet it had a huge rate of cellular respiration meaning something went wrong during the negative control trial. Similarly, the plant appeared to undergo cellular respiration under red light; however, any colors outside the ideal wavelength range were expected to undergo lower levels of photosynthesis or not have any change in carbon dioxide during the short time interval. It is possible that the leaves run under red light truly were undergoing cellular respiration rather than photosynthesis because it was too far from he accepted spectrum; however, it could also be attributed to error. More data would have to be gathered to determine whether baby spinach leaves photosynthesize or respire under red light. Of the three colors tested, the plant’s ideal absorption range is most like that of green; lying somewhere around 492 to 577 nm. Likely, the accepted range includes some values on the lower end of the spectrum because blue light also led to a rate of photosynthesis.

Many outside influences affected the recorded carbon dioxide concentration. Someone may have bumped the table, causing large spikes to occur in the graph. The same leaves were not used each time because the rates of consumption or production appeared to change as the trials continued. The leaves would not be crisp, and the rate went down even when the same color was tested. Even though the leaves were switched out to account for this error, each additional sample may have had a lower or higher rate of photosynthesis than the previous. The sensors had to be switched multiple times because of misreading as well. For example, the relatively large positive slope of 1.9618 PPM/s should not have been the slope of the negative control. In theory, the slope should have been around zero because fake leaves should neither produce carbon dioxide (cellular respiration) nor consume carbon dioxide (photosynthesis). The large deviation could have occurred due to incorrect data collection; the sensors used to record carbon dioxide levels were too sensitive and old to be of good use. Multiple sensors were used to no avail which may have meant the box connecting the computer to the sensor or the program ran awry. Several samples had a recorded carbon dioxide value of 300,000 PPM which was nowhere near the 400-1000 PPM range of the others. Additionally, it is possible that changing the sensor changed the reading slightly, impacting the gathered data. Each sensor may have worked slightly differently than the last; not every trial had the same baseline as the others. Another possible problem may have been lack of water in the solution. Ina Vasilean found that “for light to be perceived by plant tissues, one of the major conditions was reported to be the presence of water” (Vasilean et al 2018). One or more of the colors may have had a higher rate of carbon dioxide consumption if water was inside the container.

While the experiment did include many errors, many other researchers had similar results for the effect of light’s wavelength on plants. Even though Ina Vasilean, along with other researchers, studied the effect of light wavelength (color) on the germination performance of three different types of legumes, it is important to understand the effect of light on more than just spinach leaves. Oftentimes, there are similarities, and the findings can be applied to other plants. For each plant, the accepted wavelength range varied, meaning some light led to more germination than others. Lentils grew best under violet light (405 nm) and the red light (700 nm) which is somewhat surprising because those wavelengths are relatively far apart. They found that “broad bean germination under light also presented a significant improvement of total protein content and antioxidant activity” (Vasilean et al 2018). There results highlight that increased rates of growth occur under different colors of light, and that each species has its own range of wavelengths it can observe.

Sofia Carvalho and Kevin M. Folta wrote about the effects of light wavelength (color) on a variety of species including spinach. The study found that “spinach biomass is increased when grown under blue-rich light sources, whereas repressed by monochromatic red” (Carvalho and Folta 2014). They also found that blue light combined with others led to increased biomass. This is similar to what was found experimentally in lab as well. Spinach appeared to produce carbon dioxide under red light (cellular respiration) while it consumed carbon dioxide under blue, green and white light. Within our experiment, the green light led to the highest rate of photosynthesis; however, it is possible that a mix of blue and some other color would have led to an even higher rate.

Undernourishment is a large problem globally, “reaching an estimated 821 million in 2017”

(Fao.org 2018). Additionally, the population of the world is continuing to increase, leading to more people with about the same amount of food. To fix this problem of malnourishment and feeding a global population, plants should be grown in the conditions that promote nutritious, large crop yields. By understanding what each color of light does for the plants, a “balance between fast growth, nutritional value and human safety must be considered when designing optimal light conditions for spinach growth” (Carvalho and Folta 2014). Studies have found that “exposure to different light-emitting diodes (LED) wavelengths can induce the synthesis of bioactive compounds and antioxidants, which in turn can improve the nutritional quality of crops”; however, some dangerous chemicals are produced as well (Vasilean et al 2018). By knowing which lights induce which characteristics, a combination of wavelengths can be found to grow a variety of nutritional plants to decrease the rate of world hunger and feed mankind for generations to come.

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