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The Effects of Light Color on the Rate of Photosynthesis in Living Leaves

Abstract

This lab investigation serves to study the factors that affect the rate of photosynthesis in living leaves. Light is essential in photosynthesis and different colored lights were tested on spinach leaf cells. White light appears to be the most effective light for photosynthesis, but apart from white, red light is also effective. When white light is not used, red is more effective than its counterparts, most likely because red light has a long wavelength that allows it radiate more energy and heat than other colors. The wavelength of a color is directly related to the rate of photosynthesis, with longer wavelengths leading to higher rates of photosynthesis.

Introduction

The primary focus of the lab was to test what factors affected the rate of photosynthesis in living spinach leaves. Photosynthesis is the process by which plants create organic molecules from water, carbon dioxide, and light. The general summary equation for photosynthesis is:

$$2\,H_2O + CO_2 + light \ \rightarrow carbohydrate\ (CH_2O) +\ O_2 +\ H_2O$$

Photosynthesis takes place primarily in the leaves of plants. The structure of the leaf consists of the upper and lower epidermis, the mesophyll, the vascular bundles, and the stomates (Carter). The upper and lower epidermises serve mainly as protection for the leaf, and the stomates only function in air exchange. Carbon dioxide enters through the stomates and oxygen gas exits. The vascular bundles are the plant's transportation system; all water and nutrients moves via the vascular bundles to different parts of the plant. Chloroplasts are only found in mesophyll, and that is where photosynthesis occurs.

The spongy mesophyll layer of a leaf normally contains various gases, like oxygen and carbon dioxide. As a result, leaves float in water. Consequently, if a vacuum is created and the gases are drawn out of the leaf, the leaf would be expected to sink because of its increased density. In order for the leaf to perform photosynthesis, the plant needs access to carbon dioxide as well. Bicarbonate ions dissolved in water would be a way of allowing a leaf to perform photosynthesis while submerged in water. As the leaf performs photosynthesis, however, oxygen is produced and accumulates in the air spaces within the mesophyll. When cellular respiration occurs, oxygen is consumed so the two processes counter each other. Therefore, the oxygen that ends up in the mesophyll after both processes is the net rate of photosynthesis occurring in the tissue.

The light source a plant is under greatly affects the rate of photosynthesis. All light and its color variations have a specific wavelength associated with them. A wavelength is defined as the distance from the top of one wave to the top of the next (Russell). Light with wavelengths ranging from 400 – 700 nanometers (nm) is known as visible light (Madigan). The visible colors from shortest to longest in terms of wavelength are as follows: violet, blue, green, yellow, orange, and red. According to scientists like Samuel Pierpont Langley, light with longer wavelengths have the ability to radiate more energy in the form of heat (Madigan). Langley passed light through a prism and discovered that light with a wavelength beyond 700 nm, infrared light, makes other objects warm.

To test how the color of a light source affects the rate of photosynthesis in plants, an experiment was performed. If spinach leaves are placed under red, blue, and white light, the plants will have the highest rate of photosynthesis under the red light. This is due to the fact that red light has the longest wavelength of all visible light, allowing it to radiate more energy to the plant. To test this, three medicine cups contained 10 spinach leaf disks each that had air pulled out of their mesophyll layers. These three cups were then placed under varying colored light sources and the rate of photosynthesis was analyzed in the form of net oxygen production.

Safety Procedures

You must wear safety goggles, aprons, and gloves because you will be working near light bulbs that can easily shatter. Keep all solutions away from the electrical cord of the light source, and never heat a solution above 50-60°C. Also, test syringes beforehand to see if they are capable of withstanding the vacuum created in this procedure.

Procedure

Materials

- 250 ml beakers
- 150 ml of tap water
- Baking soda (sodium bicarbonate)
- White 18-watt CFL light bulb
- Red 13-watt CFL light bulb
- Blue 13-watt CFL light bulb
- 3 Lamps
- Metric scale

- 3 30 cc (ml) cups
- Liquid soap
- Pipette
- Plastic syringe without needle (10mL or larger)
- Living spinach leaves
- Hole puncher
- Timer
- Stirring rod

Using a metric scale, measure out 1.5 g of sodium bicarbonate. Fill a 250 ml beaker with 150 ml of water and use a stirring rod to dissolve 1.5g of sodium bicarbonate in it. Pour the bicarbonate solution in 3 30 CC(ml) cups to a depth of about 3 cm each. Using a pipette, add one drop of liquid soap to each cup, avoiding suds. Next, use a hole punch to cut 30 spinach leaf disks while avoiding leaf veins. Then, create a vacuum by first removing the plunger from a plastic syringe and placing 10 spinach leaf disks into its barrel. Push the plunger back in until there is 1 cm^3 of air left in the barrel and pull 5 cc of sodium bicarbonate solution from a cup into the syringe. Tap the syringe to suspend the spinach leaf disks in the solution. Flip the syringe upside down and push out any air. Next, hold a finger over the syringe's opening, draw back the plunger, and hold for 10 seconds. Then, release the vacuum by removing your finger to let the plunger spring back. Pour the spinach leaf disks and the solution from the syringe back into its cup. Repeat this procedure for the other 2 cups. Afterwards, attach a red 13-watt CFL light bulb, a blue 13-watt CFL light bulb, and a white 18-watt CFL light bulb to three different lamps on a counter. Use a metric ruler to position each lamp so that each bulb is 8 cm above the counter. Then, place each cup of spinach leaf disks and bicarbonate solution under different lamps. Start the timer and record the number of floating disks after every minute in Table 1 until ½ of all leaf disks in each cup are floating.

Results/Data Collection/Analysis

In short, the data from the experiment demonstrated that the rate of photosynthesis of leaf disks varied depending on the color of the light source. White light appeared to be the most efficient light source for photosynthesis in spinach leave cells.

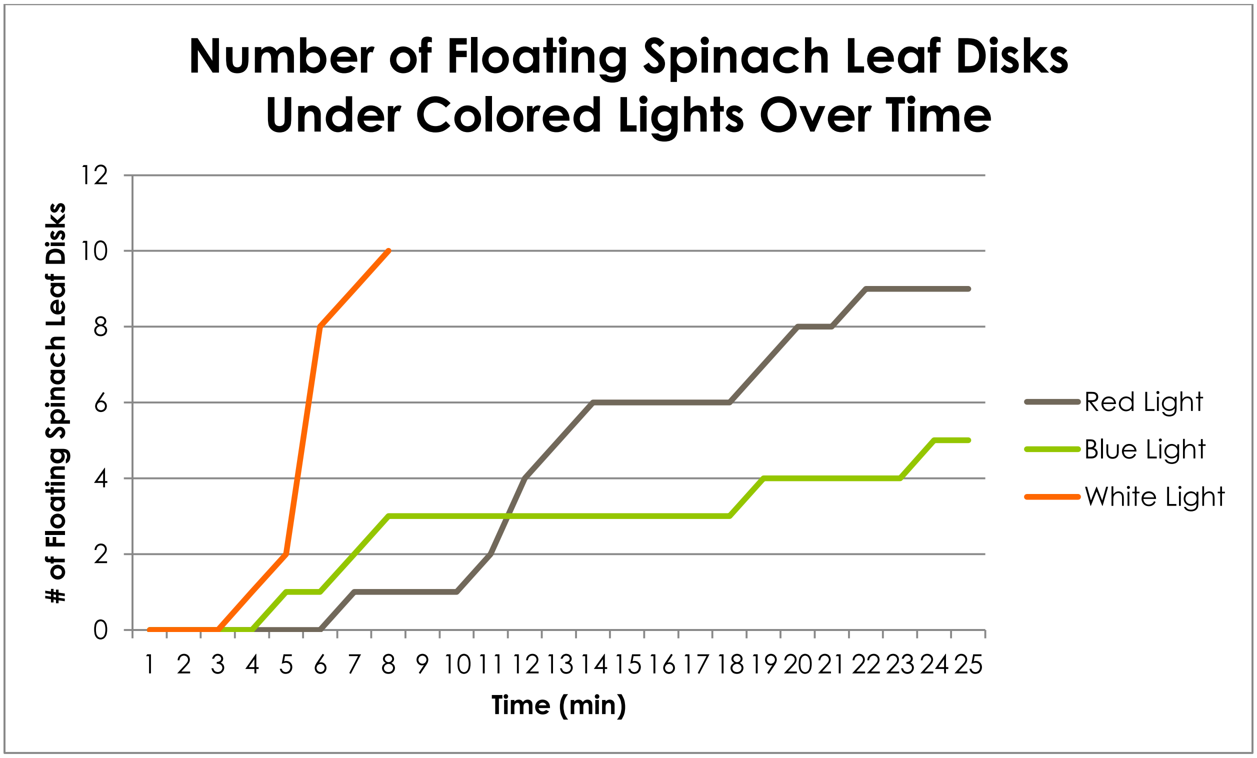
Table 1: Number of Floating Spinach Leaf Disks under different Colored Lights over Time

Minutes	Red Light	Blue Light	White Light
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	1
5	0	1	2
6	0	1	8
7	1	2	9

8	1	3	10
9	1	3	
10	1	3	
11	2	3	
12	4	3	
13	5	3	
14	6	3	
15	6	3	
16	6	3	
17	6	3	
18	6	3	
19	7	4	
20	8	4	
21	8	4	
22	9	4	
23	9	4	
24	9	5	
25	9	5	

Table 1 above shows that the spinach leaf disks had the highest rate of photosynthesis under white light. In addition, the data also demonstrates that the spinach leaf disks had higher rates of respiration under the red light than the blue light. Each plastic cup had only 10 spinach leaf disks and was placed 8 cm below its respective light source.

Figure 1: Number of Floating Spinach Leaf Disks under Colored Lights over Time



In Figure 1, spinach leaf disks floated the fastest under white light. The goal of the experiment was to observe how long 5 spinach leaf disks took to float in a sodium bicarbonate solution. The leaf disks under the red light floated slowly at first but sped up as time went on. The leaf disks under the blue light floated quicker than those under the red light at first but slowed down over time.

Discussion

The original question of the experiment was to observe what factors affect the rate of photosynthesis in living leaves. Light, as indicated by the data below, appears to play a major role in the photosynthesis of plants. The hypothesis that the spinach leaf disks under red light will have the highest rate of photosynthesis was not supported by the data.

Table 2: Estimated Time it takes 50% of Spinach Leaf Disks to Float under Colored Light

	Red Light	Blue Light	White Light
ET_{50}	13 min	24 min	~6 min

In the table above, 5 of the 10 spinach leaf disks floated the fastest when under white light. It took about twice as long for half of the spinach leaf disks under the red light to float. The spinach leaves under the blue light also took almost twice as long as the spinach leaf disks under the red light to float. The ET_{50} value above represents the amount of time it took for 5 out of the 10 spinach leaf disks in a cup to float. The shorter the ET_{50} value, the higher the rate of photosynthesis.

It appears that white light was most effective in photosynthesis because it offered a large spectrum of colors. The red and blue light bulbs offered a narrow range of colors, perhaps outside the preferred range that was optimal for photosynthesis. There are, after all, various shades of red and blue – perhaps the shade of red and blue used was not as effective as the multitude of colors within white light. Many kinds of pigments exist in a plant cell, so whereas single-colored lights allowed one type of pigment to become active, white light allowed all the pigments in a cell to be active. This makes sense since there are two major chlorophyll pigments: *a* and *b*. This also could explain why the ET_{50} value of cups under white light was half of its nearest competitor. Twice the amount of chlorophyll was active under white light, so half of all the spinach leaf disks rose twice as fast as those under red light.

The notion that longer wavelengths of light lead to higher rates of photosynthesis is uncertain. The extra energy or heat that red light carried may not prove to be very effective in increasing the rate of photosynthesis. However, red light is still more effective than blue light. Apart from white light, which is an amalgamation of all colors, it appears that colored light with longer wavelengths are indeed more effective than colored light with shorter wavelengths.

Some possible errors include improperly designing a control. Using artificial white light begs the question of how “white” the light was. In addition, the white light bulb had more watts, 15 compared to the 13 of the colored bulbs. Also, since this is an experiment rather than an observational study, a placebo should be used. If light alters the rate of photosynthesis, then perhaps are more effective control would have been allowing the leaves to float without any light bulb overhead. In future experiments, the light bulbs should be identical in every measure except for their color, and an extra placebo should be added that is not associated with a light bulb.

Conclusion

In summation, the rate of photosynthesis in plants does depend greatly on a light source. White light is the most effective light for photosynthesis because it provides a wide range of colored lights for various pigments to use. When only a single color is used, red is the most effective color of light. Red has a long wavelength, allowing it to radiate more energy and allow for an increased rate of photosynthesis in plants. This lab proved that the length of a wavelength of light a plant is exposed to is directly related to the rate of photosynthesis. In addition, more colors available for the plant allow more pigments to be activated, also leading to higher rates of photosynthesis.

This investigation aided in developing better precision and delicacy with materials. The spinach leaf disks had to be cut carefully, avoiding veins, and had to be protected while in the syringe. Creating too many vacuums or crushing the leaves could create sources of error. The experiment also helped teach experimenters how to make better inferences with data collected and how to think outside the box for these inferences.

Questions

- How does the intensity of light affect the rate of photosynthesis?
- How does the concentration of carbon dioxide affect the rate of photosynthesis?
- Do all plants photosynthesize more than they respirate?
- How does temperature affect the rate of photosynthesis?
- What factors affect a plant’s rate of cellular respiration?

References

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