Effect of Light Color on Rate of Photosynthesis

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Colored Light and Plant Growth

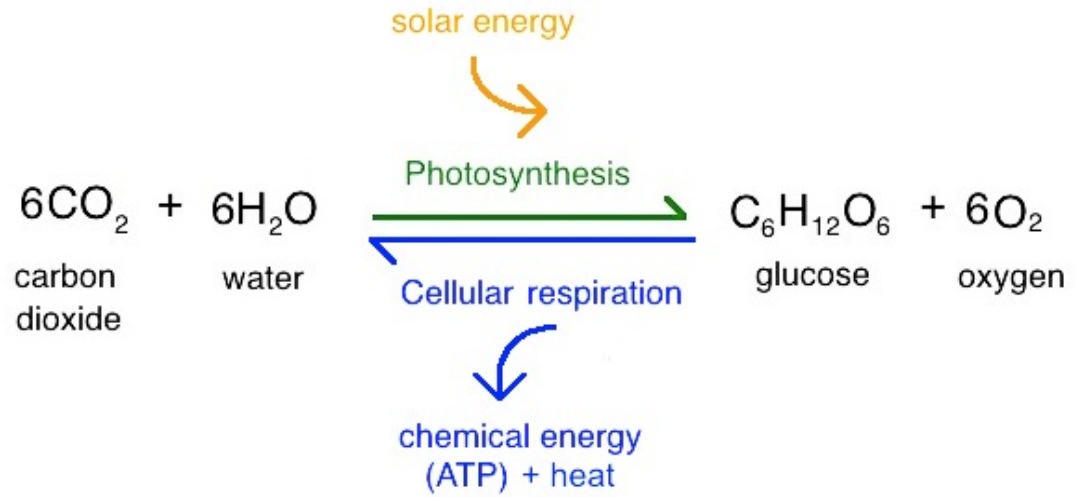
Colored light is used in growing labs to improve plant growth efficiency. It seems that growing plants with colored lights is a potential method to improve the growth rate of food. As food resources are limited for the world population, this investigation is relevant to help solve these issues. If vegetables or fruits are grown with colored light, the required growing time or overall yield could increase, therefore improving the efficiency of food production. Many different colors of light could potentially be used so it is important to investigate which colors are best for growing plants.

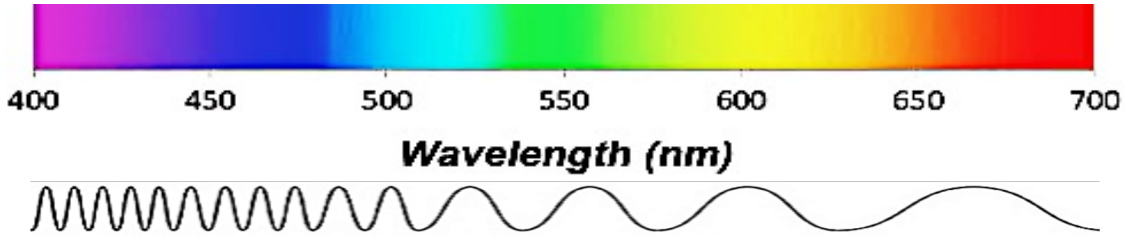
HyCube Vertical Farm in Orlando, Florida

Photosynthesis and Light

In photosynthesis, plants use light to convert water and carbon dioxide to sugars and oxygen. Photosynthesis takes place in chloroplasts, which contains chlorophyll to absorb light energy.

The wavelength of light corelates with its amount of energy. Not all wavelengths are used equally as pigments only absorb some wavelengths of visible light while reflecting other wavelengths.

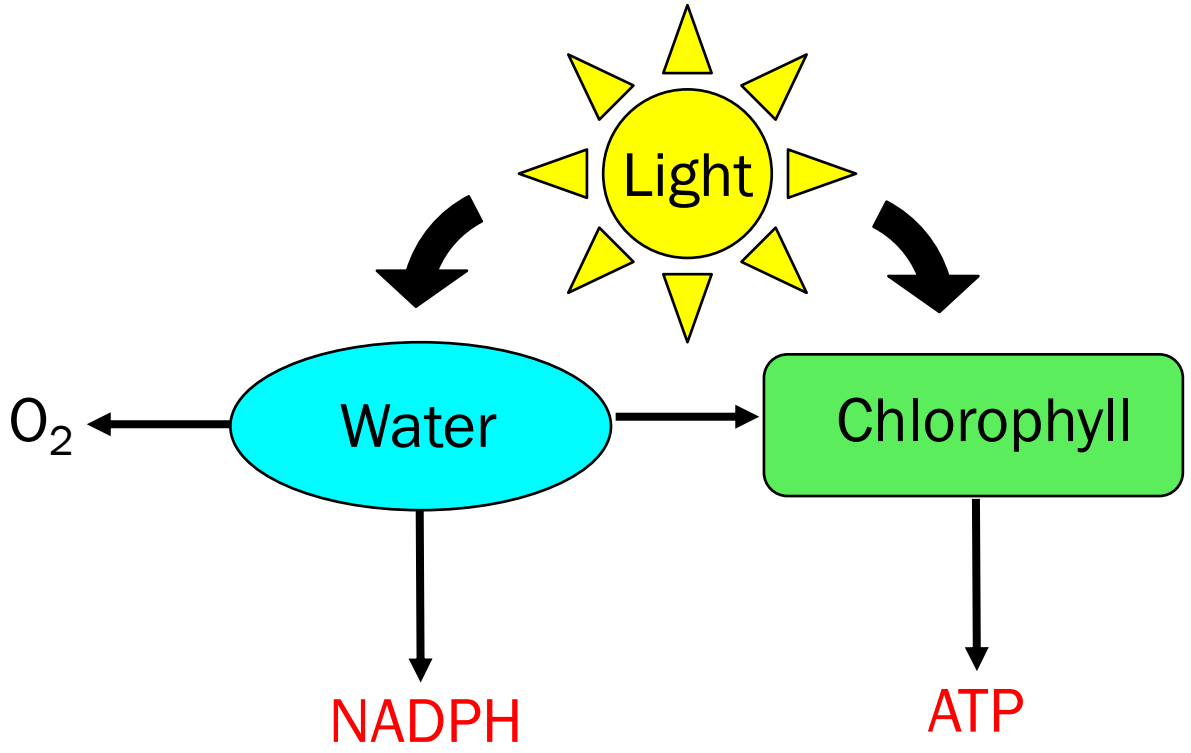




Photosynthesis and Light

When a pigment absorbs a photon of light, it becomes excited. Only photons with the right amount of energy can successfully excite a pigment. The photons are used with water to produce ATP and reduced NADP in the light dependent reactions.

ATP and reduced NADP are then used in the Krebs Cycle of the light dependent reactions where glucose is produced for plant growth or storage.



Research Question

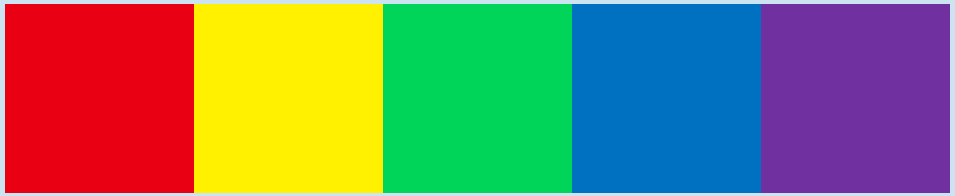
What is the effect of red, yellow, green, blue, and violet light on the rate of photosynthesis of *Ludwigia repens* in 20 cm^3 of 2% $NaHCO_3$ measured by the volume of oxygen produced per minute over 10 minutes?

Ludwigi *repens*

Hypothesis

Ludwigia in blue and violet light will have the fastest rate of photosynthesis. This is because blue and violet light have the most energy, so they will excite electrons more quickly. Additionally, green light will cause the slowest rate of photosynthesis because Ludwigia plants are green, so they reflect more green light than any other color.

Variables

Independent Variable	Dependent Variable
The color of light shone on *L. repens* (red, yellow, green, blue, and violet). The change in light color will be achieved by colored plastic sheets. These five colors were chosen to cover the range of the visible light spectrum. 	The rate of photosynthesis measured by the volume (cm^3) of oxygen produced per minute.

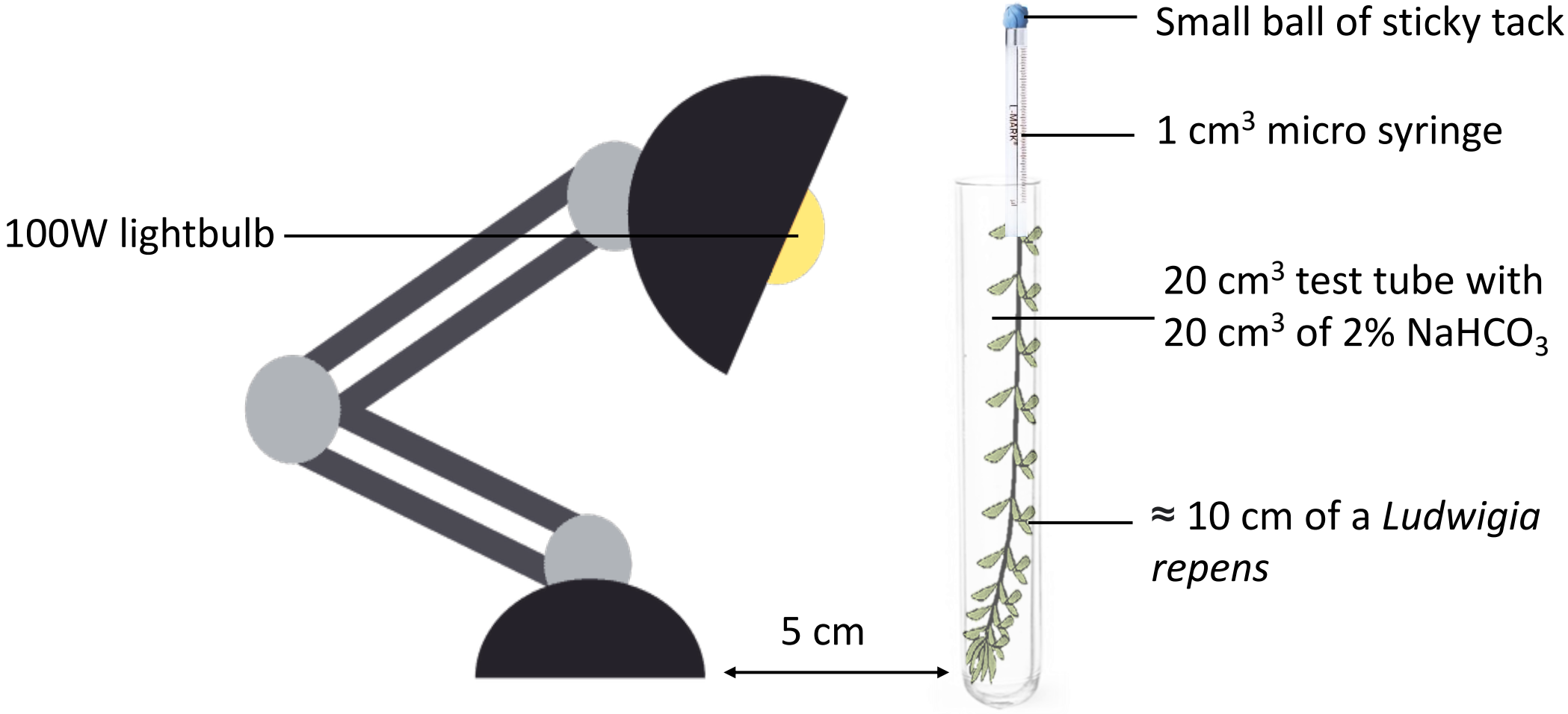
Variables

Controlled Variables	Method to Control Variable
Species of Pond Weed	Ludwigia *repens* were used in all trials.
Light Intensity (distance from lamp in cm)	The lamp was positioned 5 cm from the test tube in all trials.
Concentration of $NaHCO_3$ Solution (mol dm^3)	500 cm^3 of a 2% $NaHCO_3$ solution was prepared and the same solution was used in all trials.
Room Temperature (˚C)	All trials were performed at room temperature, which was 22˚C.
Color and Opacity of Water	A solution of clear and colorless 2% $NaHCO_3$ was used in all trials.

Apparatus

- 500 ± 0.5% cm^3 Beaker
- 20 ± 1 cm^3 Test Tube
- 1.0 ± 0.5 cm^3 Micro Syringe
- 100W Lightbulb
- 500 cm^3 of Water
- 10 g of Sodium Hydrogen Carbonate (Baking Soda)
- 6 *Ludwigia repens* Plants
- 10 ± 0.04 cm^3 Pipette
- Lamp
- Red, Yellow, Green, Blue, and Violet Colored Plastic Sheets
- Electronic Scale ± 0.01 g
- Scissors
- Sticky Tack
- Tape
- Test Tube Rack
- Timer ±0.05 min
- Tweezers

Set Up


100W lightbulb
5 cm
Small ball of sticky tack
1 cm³ micro syringe
20 cm³ test tube with
20 cm³ of 2% NaHCO₃
≈ 10 cm of a *Ludwigia repens*

Set Up

Ludwigia *repens*

Sample Test Tube from Experiment

Method

1. Pour 500 cm^3 of water into a 500 cm^3 ± 0.5% beaker.
2. Weigh 10 g of sodium hydrogen carbonate on scale and add to beaker with water.
3. Mix solution in beaker until completely dissolved.
4. Use a 10 cm^3 pipette to transfer 20 cm^3 of the solution to a 20 cm^3 test tube.
5. Place a 100 cm *L. repens* stem upside down in the test tube ensuring plant is submerged.
6. Cut a diagonal slit on the end of the stem while keeping the end of stem submerged.
7. Wrap the test tube fully in red colored filter paper.
8. Place test tube in a test tube rack positioned 5 cm away from a 100W lightbulb.

Method

9. Fill a 1 cm^3 micro syringe completely with the sodium hydrogen carbonate solution.

10. Place small ball of sticky tack on end of syringe to keep water in syringe.

11. Place syringe on the end of the stem, ensuring that bottom of the syringe is submerged.

12. Record volume of oxygen in micro syringe every 1 minute for 10 minutes.

13. With the same *L. repens*, repeat steps 4-11 with yellow, green, blue, purple, and no colored filter paper wrapped around test tube.

14. Repeat steps 4-13 with four more different *L. repens*. Also replace sodium hydrogen carbonate solution between each plant.

Safety and Ethical Concerns

There are no ethical concerns in this experiment. Ludwigia was obtained from a local pet store. Disposal of Ludwigia should be in garbage to avoid introduction of alien species into environment. 2% sodium hydrogen carbonate solution can be disposed in a normal drain.

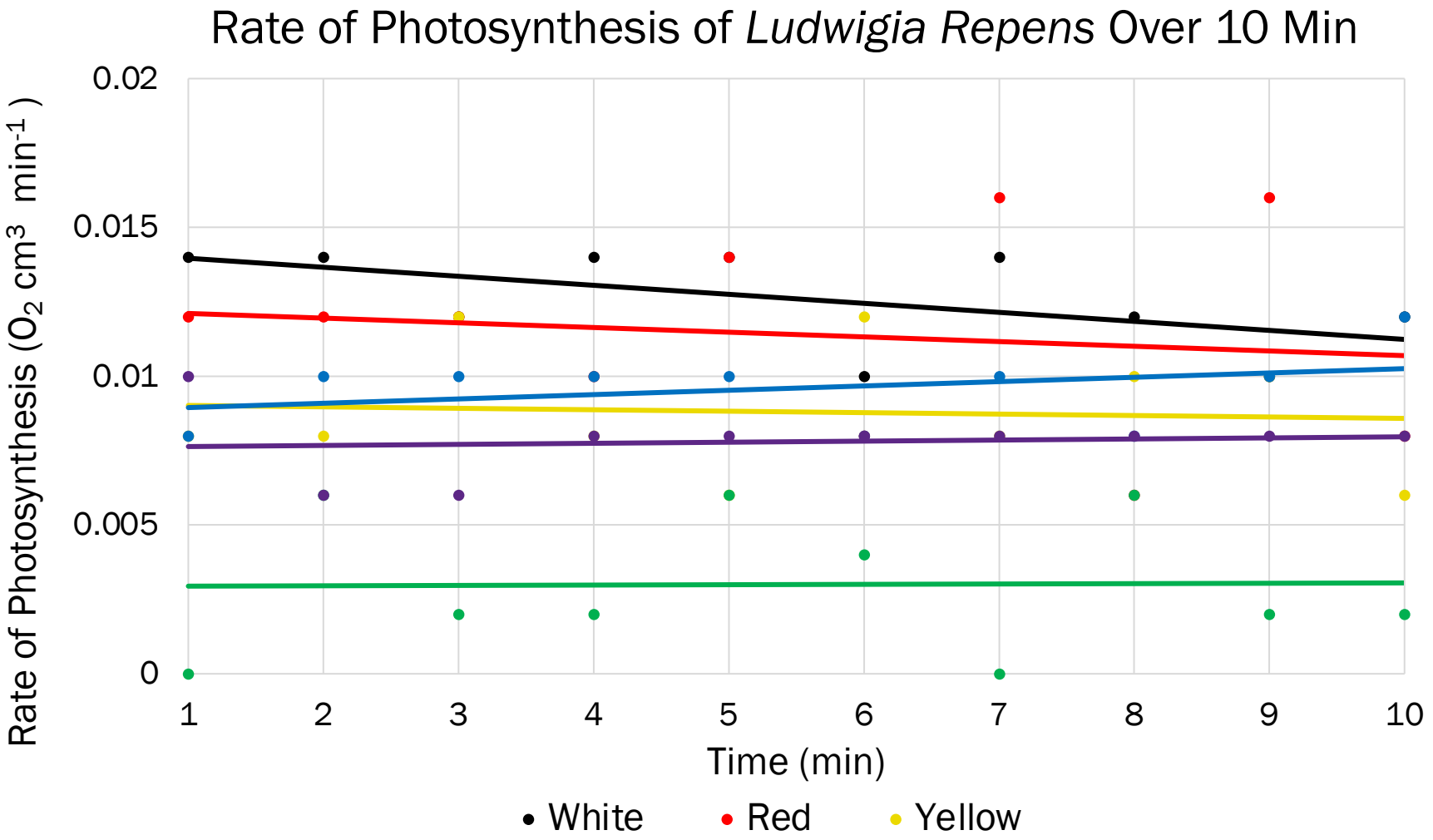
Other: Observations

White Light	Tiny oxygen bubbles constantly streamed from tip of stem. Bubbles were released very frequently.
Red Light	Tiny oxygen bubbles constantly streamed from tip of stem. Bubbles were released frequently.
Yellow Light	Tiny oxygen bubbles constantly streamed from the tip of stem. Bubbles were released frequently.
Green Light	Tiny oxygen bubbles streamed from tip of stem. Bubbles were released very slowly with frequent pauses.
Blue Light	Tiny oxygen bubbles constantly streamed from tip of stem. Bubbles were released frequently.
Violet Light	Tiny oxygen bubbles streamed from tip of stem. Bubbles were released slowly with occasional pauses.

Sample Raw Data (1 of 5 trials)

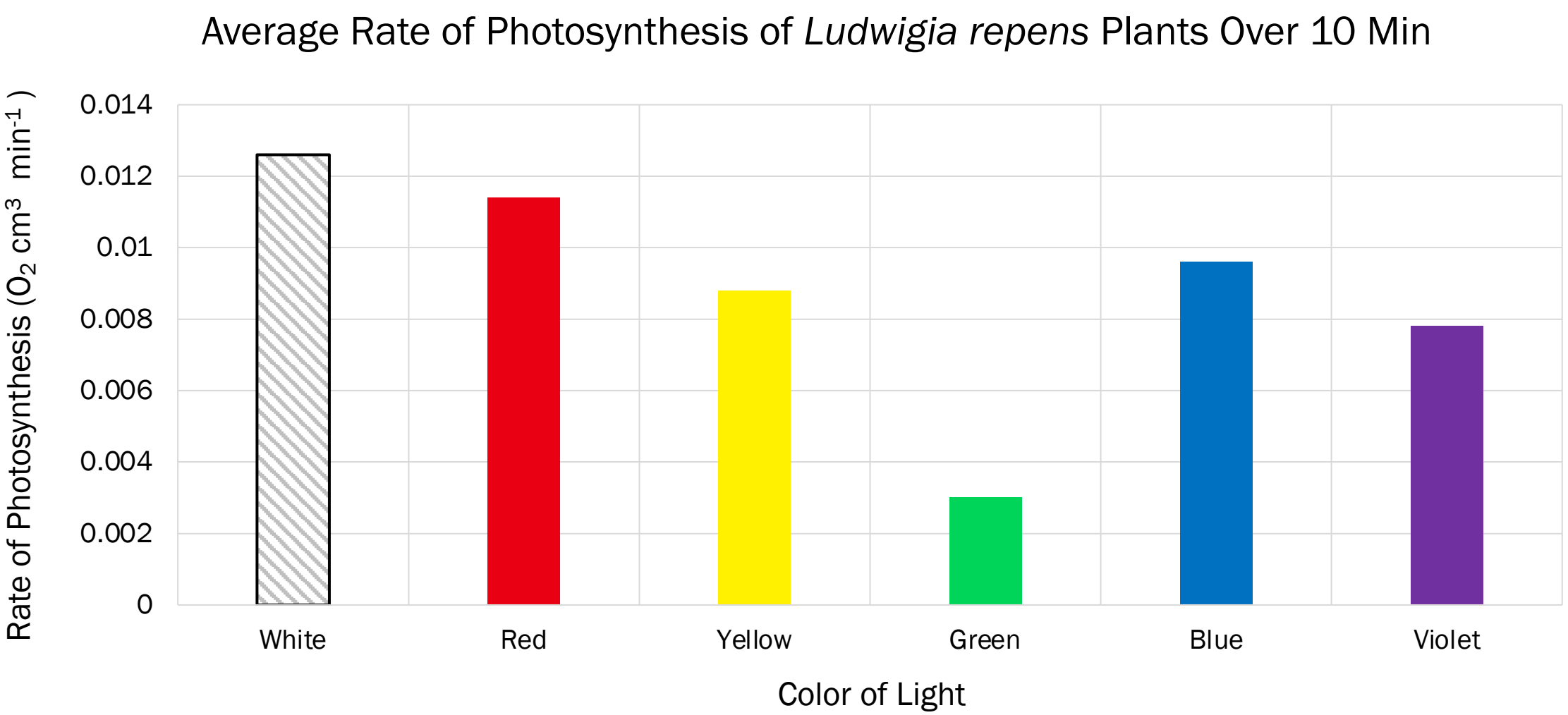
Time (±0.05) min	Volume of O_2 for White Light (±0.5) cm^3 x 0.1	Volume of O_2 for Red Light (±0.5) cm^3 x 0.1	Volume of O_2 for Yellow Light (±0.5) cm^3 x 0.1	Volume of O_2 for Green Light (±0.5) cm^3 x 0.1	Volume of O_2 for Blue Light (±0.5) cm^3 x 0.1	Volume of O_2 for Violet Light (±0.5) cm^3 x 0.1
0	5.4	5.0	5.8	4.8	5.0	5.4
1	5.6	5.3	6.0	4.8	5.1	5.6
2	5.8	5.5	6.1	4.8	5.2	5.7
3	6.0	5.7	6.3	4.9	5.3	5.7
4	6.3	5.8	6.5	4.9	5.4	5.8
5	6.5	6.0	6.6	5.0	5.5	5.9
6	6.7	6.2	6.7	5.0	5.6	6.0
7	7.0	6.5	6.9	5.0	5.7	6.2
8	7.3	6.6	7.0	5.1	5.7	6.3
9	7.5	6.9	7.2	5.1	5.8	6.4
10	7.7	7.1	7.4	5.1	5.9	6.5

Processed Data



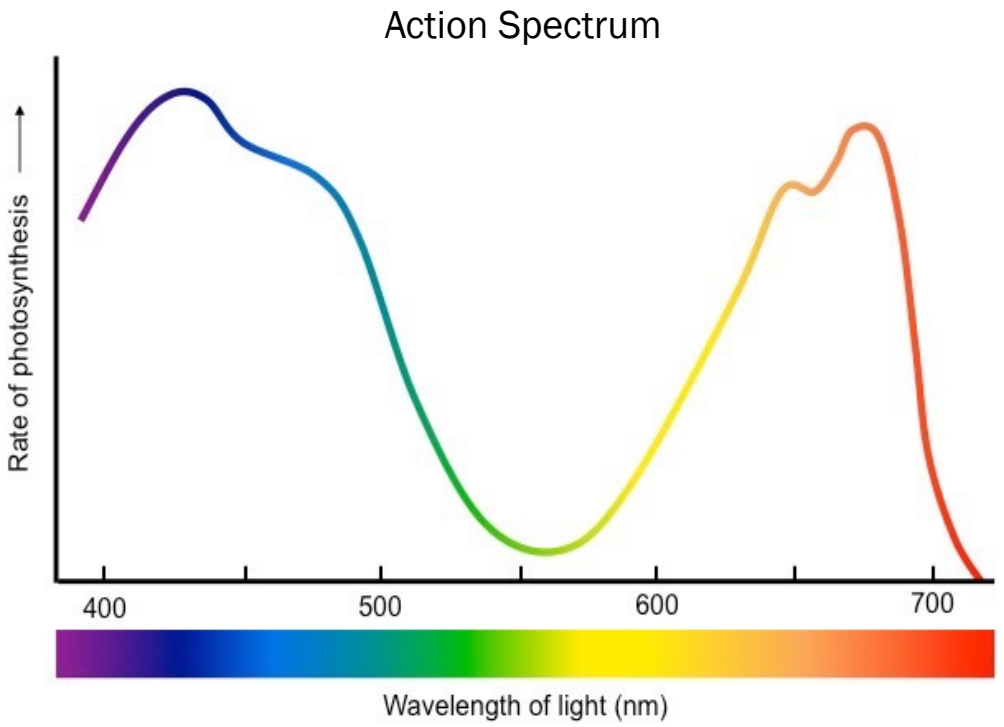
	Mean	Std Dev
White Light	0.013	0.002
Red Light	0.011	0.003
Yellow Light	0.009	0.002
Green Light	0.003	0.002
Blue Light	0.010	0.001
Violet Light	0.008	0.001

Processed Data



Graph Explanation

The data is shown in a bar graph to mimic the action spectrum of photosynthesis. Since only 5 colors were tested, there cannot be a continuous line between each color like in the action spectrum. The trend in photosynthesis rates along the visible light spectrum can still be observed. The graph is similar to the action spectra in that the two highest rates are red and blue-violet. Additionally, green has the significantly lower rate in both graphs.



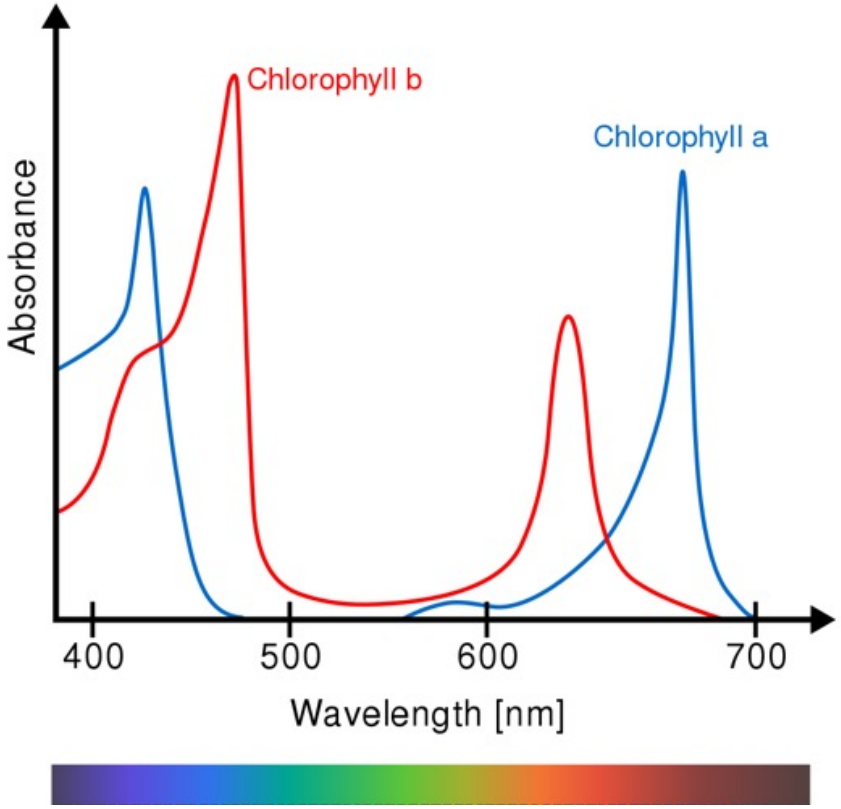
Conclusion

The results show that the average photosynthesis rate was greatest for white light at 0.013 O_2 cm^3min^{-1}. With a colored filter applied, the greatest photosynthesis rate was for red light at 0.011 O_2 cm^3min^{-1}. White light resulted in the highest photosynthesis rate since it required no plastic filter which restricts light reaching the Ludwigia, so the light intensity was greatest. The lowest rate of photosynthesis was green light at 0.030 O_2 cm^3min^{-1} by a significant difference. In addition to the calculated rate, this trend was observed as oxygen bubbles were released very frequently for white and red light and very infrequently for green light. The results support some parts about the hypothesis. It is supported in that green light had the slowest rate of photosynthesis. However, red light had the highest rate of photosynthesis instead of blue and violet light.

Explanation

Chlorophyll A is present in all plants that perform photosynthesis and absorbs violet-blue and orange-red light. Chlorophyll B also primarily absorbs red light and some blue light.

In this investigation, red and blue light had the highest rate of photosynthesis. Violet and yellow light are close to red and blue light on the visible light spectrum. This explains why their rates of photosynthesis were close, but slightly lower than red and blue light. Neither chlorophyll A or B absorb green light and they instead reflect it. This explains the green color of the Ludwigia and the reason that green light caused the slowest rate of photosynthesis.



Absorption Spectrum of Chlorophyll A and B on Visible Light Spectrum

Sources of Error

1. Human judgment was used to measure the volume of oxygen in the micro syringe. This could result in inaccurate measurement readings since it involves estimation to read the instrument. The volume of the oxygen could have been slightly too high or too low depending on how the measurement was rounded.

2. The volume of oxygen produced was only recorded over a period of 10 minutes. This provided a fairly small range of data points for each trial.

3. The volume of oxygen was recorded once per minute. This means when the volume of oxygen changed more than one graduation in a minute, the exact rate could not be measured.

Sources of Error

4. The transparent plastic sheets had slightly different transparency levels, which caused the light intensity to slightly vary for each color. Photosynthesis is affected by light intensity, so this could had led to higher or lower rate of photosynthesis than expected. The yellow filter sheet was slightly more transparent, which explains why the rate of photosynthesis for yellow light was higher than expected.

5. The 5 Ludwigia stems used in each trial all came from the one main plant. While the results show a trend in photosynthesis for that particular plant, biological variation means that the results cannot be certain for other Ludwigia plants.

6. Only five colors of the visible light spectrum were tested. This provides a general trend in the rates of photosynthesis, but the trend is very limited as only five points are considered.

Potential Improvements

1. A method to increase accuracy of the volume readings is to use a meniscus reader on burettes and graduated cylinders. The reader can also position themselves to be eyelevel with the meniscus to reduce parallax error.

2. A possible improvement is to record the volume of oxygen produced for a longer time, such as one hour. This would give more accurate results for the rate of photosynthesis.

3. The measurement of oxygen could be improved by recording the volume of oxygen more times per minute, such as every 10 seconds. This would give far more accurate measurements and therefore lead to lower uncertainty.

Potential Improvements

4. A potential improvement for this limitation for light limitations is to use LED lights instead of transparent plastic sheets. Therefore, the light intensity could be controlled more easily as the color would come directly from the light source.

5. To improve the biological limitation, each Ludwigia plant could come from a different Ludwigia plant source. This would cover a larger range of possibilities of plants, and improve the accuracy of the data.

6. To improve limitation of color choices, additional colors could be tested, such as orange, cyan, or indigo. Using more light colors would provide information about the rate of photosynthesis over the visible light spectrum.

Extension

The effects of edible plants, such as tomatoes or lettuce, could be investigated to explore results relevant to growing food. The rate of photosynthesis could also be determined by measuring the consumption of carbon dioxide or measuring the increase in dry mass. Additionally, as indicated in the evaluation of procedure, more colors could be investigated to gain a better trend in the visible light spectrum.

Applications

While this experiment provided information on the rates of photosynthesis in colored light for Ludwigia, the action spectrum can vary between plant species. However, the principles to find this information can be applied in other plants, especially edible plants. Colors of the light spectrum affect plants in different ways, such as improving growth rate or fruit yield. There is great potential to increase efficiency of food growth using colored lights. This would be beneficial in places with limited space for farming or growing populations. Using colored light with other energy and space innovative farming methods, such as vertical farming, can help make the farming industry more sustainable and provide food to more people.

Vertical Farming Facility at AeroFarms
(Largest Vertical Farm Located in UAE)

Questions?

Other: Data Processing

1. Determining Change in Volume of Oxygen Produced Each Minute ($v_f - v_i = \Delta v$)

2. Determining Average Volume of Oxygen Produced for Each Minute ($\Delta v_{av} = \frac{(\text{sum of volumes})}{(\#\text{ of volume values})}$)

3. Determining Average Rate of Photosynthesis per Minute (rate of PHS = $\frac{\Delta v}{\Delta t}$)

4. Determining Average Rate of Photosynthesis Over 10 Minutes (rate of PHS = $\frac{\Delta v}{\Delta t}$)