The Effect of Different Colors of Light on the Growth of Young Specimens of the ***Helianthus annus*** (Sunflower)

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Abstract

Different wavelengths of light in the visible spectrum, when isolated, cause different effects and stimulate specific photosynthetic pigments in an autotrophic organism. A general trend action spectrum shows the photosynthetic activity specific wavelengths possess but their effects on certain plant species could vary. A definite way to observe effects of particular wavelengths of light on growth of plants is to observe how size of growth would vary in relation to different colors of light, and an appropriate plant species to use in such an investigation is the *Helianthus annus* (Sunflower). Thereby, a research question employed was:

"How do different visible light wavelengths affect size of growth in *Helianthus annus* (Sunflower) seedlings?"

When the *Helianthus annus* experiences lack of light, it grows a long stem and small cotyledons, and in conditions of sufficient light, it grows large cotyledons and a shorter stem. So, in this investigation, the shorter the specimen, and larger the cotyledons, the healthier the plant is.

The results from this investigation showed that wavelengths of green light caused the specimens to grow tallest with the smallest cotyledons. Also, yellow light grew tall specimens with small cotyledons in accordance with the generic absorption spectra. However, the shortest specimens with largest cotyledons, which should have characteristically been shorter wavelengths (blue light), were instead in longer wavelengths of red and orange light. The shorter wavelengths grew plants much taller than expected according to the generic action spectra.

Essentially, these results suggested that the *Helianthus annus* absorbs and uses longer wavelengths of light in relation to shorter wavelengths more effectively than most plants. However, these results can be refuted since in principle, 100 specimens should have been used under each color of light to produce justifiable results, and in this investigation, due to lack of resources, only 3 were used.

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1. Introduction

Different wavelengths of light in the visible spectrum have varying effects on the growth of photosynthetic plants. This is because the different chlorophylls and carotenoids present capture and use only certain specific wavelengths of light in the visible spectrum. This is particularly intriguing because in the instance that only certain isolated wavelengths of light are provided for a plant, the resulting effect on the plant's growth may differ greatly from the plant's characteristic growth. This is why the investigation of the effect of different visible light wavelengths on the growth of seedlings was the chosen aim of this investigation.

In order to provide simplicity and ease in gathering results, it would be optimal for the plant used in this investigation to be fast growing, vertically growing, single stemmed, and not difficult to grow. This allows for quick and simple recognition of results where measurements can be easily interpreted and employed to make accurate conclusions. Also, for the sake of originality and interesting nature of results, it would be preferable that the plant had a unique characteristic in relation to different light conditions. The plant found to possess these desired qualities was the *Helianthus annus* (Sunflower). So, with a plant species chosen, the appropriate research question could be formed:

"How do different visible light wavelengths affect size of growth in *Helianthus annus* (Sunflower) seedlings?"

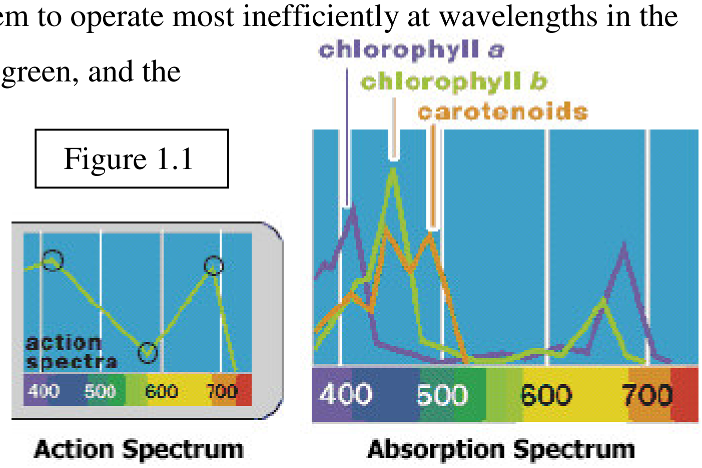
1.1 Background Information

The *Helianthus annus* is an epigeal plant, and a dicot. In its natural characteristic growth, the *Helianthus annus* emerges from the earth and quickly reverts most of its energy into its cotyledons, making them quite large. In its earliest stages, the plant has a very small stem and large cotyledons. Then after growing increasingly large cotyledons, the plant grows vertically at quite a fast rate. When the *Helianthus annus* is provided with insufficient luminous power (light), it reacts by growing small cotyledons, and a tall, weak stem[1]. The severity of these effects is proportional to the lack of light the plants experience. So this means that in this investigation, the effects of the specific colors (wavelengths) on the plants will be seen in these reactions.

1.2 Action and Absorption Spectra

Since the *Helianthus annus* is a fast-growing autotroph, one can assume that its light gathering, photosynthetic capabilities are linked to its growth in response to light. So in this investigation, results obtained for the effects of different colors of light on the growth of the plants in question will be compared with the known action spectra of different wavelengths of light in different light absorbing pigments as can be shown in Figure 1.1[2]. Both chlorophylls, *a* and *b*, as well as most carotenoids seem to function best at the lower visible light wavelengths[3]. These wavelengths contain the colors violet and blue. Then, all the light gathering pigments seem to operate most inefficiently at wavelengths in the middle of the spectrum, which are green, and the lower (darker) wavelengths of yellow. Also, several of the photosynthetic pigments themselves are green in color, so it follows that they reflect the green light and do not use it. Then, the chlorophylls a and b begin to function once again at the longer wavelengths of orange and red, before dropping off entirely. No carotenoids seem to function in this color range. This is in part since some are red or orange in pigment.

Figure 1.1



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[1] Unknown. *Sunflower Photomorphogenesis*. http://sunflower.bio.indiana.edu/~rhangart/plantmotion/earlygrowth/photomorph/sunflowerd2l/sunflowermorph.html. 10.06.2003

[2] Unknown. *thinkwell - Biology Lecture Notes – Photosynthetic Pigments*. http://www.thinkwell.com/marketing/sampleNotes/BIO_note.pdf. 09.06.2003

So, based on the known information of the photosynthetic action spectra, and of the healthy growth pattern of the *Helianthus annus*, it is possible to predict which colors out of the six being investigated will allow the plants to grow most efficiently.

It would seem correct to assume that the best growth would be in the control variable light, the full spectrum bulb, because it would stimulate pigments at all wavelengths of the spectrum. Then, in descending order would follow, the blue, red and orange, yellow, and finally the green light.

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[3] Jones, M., Jones, G. *Advanced Biology*. 1997. Cambridge University Press, Cambridge, United Kingdom

2. Experimental Method

2.1 Introduction

Three separate plants separate pots were used for each color of light in order to reduce some systematic error that might arise. Once the *Helianthus annus* seeds had germinated and were planted in each of their specific pots, the pots were simultaneously soaked in water for 30 minutes to fully saturate the soil around them and give each plant the exact same starting environment. This worked to limit errors among the plants on their emergence from the soil such that any initial differences in height would correspond only to the seed and not to the soil. Then, to ensure that the plants were all given an equal constant water supply, water trays filled with water were placed underneath the pot of each plant for the duration of the investigation.

During the investigation at the determined times when the plants were measured and readings were taken, the plants were exposed to foreign light for the time it took to measure them. To avoid this affecting the results, the single front board containing the plants within the environment was lifted during measurements. Hence, when the door opened, all the plants were exposed simultaneously for equal times to foreign light until all measurements were taken.

In order to increase practicality and precision of results, temperature and humidity were measured with a dual electronic thermometer and barometer. Also, to provide increased accuracy of readings, the measurements of the environmental conditions in the apparatus were taken through the ventilation holes of the apparatus for each individual compartment before opening the apparatus. This ensured that conditions inside were as unaffected as possible by the outside environment.

With error reduction and a prepared apparatus finished, it became necessary to decide which variables in the plants' growth and which conditions in the apparatus to monitor.

The primary variable measured in this investigation was the vertical growth of each individual plant. This provided most of the basis for the conclusions of the investigation.

Temperature and humidity were not measured, but were closely monitored to maintain they were at constant and optimal levels since they are major parts of the environment encompassing the plants at all times.

2.2 Apparatus

Having chosen a plant with appropriate qualities, the proper apparatus for containing the plants needed to be constructed. Due to the qualities of the plant and the nature of the investigation, the apparatus had to be constructed to certain specifications. These specifications would be the dimensions, the structure, and the functions of the apparatus.

The investigation takes place under 6 different colors of light, for which each has its own individual 25-watt bulb to provide light. These bulbs are chosen as 25-watt so as not to be too powerful and produce too much heat in the restricted space where they would be placed. The colors of the bulbs used are the 5 main colors in the visible spectrum: red, orange, yellow, green, and blue, and one control light: full spectrum, for which a special 25-watt bulb was obtained. This special bulb was different in structure, but since the wattage is the same as the others, this should not make a difference.

The apparatus provided a closed environment for the plants to control certain climatic variables such as moisture content, temperature, and airflow within the apparatus. Temperature is an especially important variable because the optimal temperature for the *Helianthus annus* is 65 to 75 degrees Fahrenheit[4], so this was regulated to obtain optimal results and prevent the presence of any unneeded variables for growth.

To separate the different colors of light, the apparatus had six compartments to isolate the light wavelengths desired and keep out any others. The dimensions of the apparatus were determined according to several factors. There was sufficient space for unchecked plant growth that would be safe from radiation from the light bulbs, and enough space for ventilation and airflow. There wasn't too much space however, for danger of

[4] Unknown. *Sunflower Photomorphogenesis*. http://sunflower.bio.indiana.edu/~rhangart/plantmotion/earlygrowth/photomorph/sunflowerd2l/sunflowermorph.html. 10.06.2003

overextending boundaries of the controlled environment and losing control of some of the environmental factors.

So, the design of the apparatus constructed with these qualities is shown in Appendix 7.

2.3 Method

Forty-six seeds of *Helianthus annus* species were placed in a moist environment for three days to germinate. Upon germination, eighteen seeds from approximately the same stage of germination were selected from the given forty-six to be planted and used for the investigation.

Eighteen separate moderately sized clay pots were filled to the brim with potting soil and soaked in water for one hour. After soaking, a single seed of *Helianthus annus* species was promptly planted ½ inches (approximately 1¼ cm) in the soil. Immediately after this, the pots containing their specific seeds were placed in their own separate water trays full with water. Then, the pots and their trays were placed into the six compartments in the apparatus; three to each compartment. The door to the apparatus was then sealed, producing a contained environment allowing no light to enter or escape. On doing this, the experiment began, with planned duration of seven full 24-hour days.

At regular 12-hour intervals, the door to the apparatus was opened, and readings and replenishing of the environment within the apparatus occurred. The height (in cm) of each individual plant was measured and recorded. The water trays beneath each clay pot were refilled to provide a continuous water supply. Each plant in each compartment was checked for abnormal or notable changes of any kind other than normal growth. Upon finishing this, the door to the apparatus was resealed.

3. Results and Discussion

3.1 Introduction

The investigation was completed twice for a wider range of results upon which to base experimental conclusions. The first trial of the investigation is simply presented as extra reference for the second trial, which produced the results that were used in this investigation.

In the first trial, the pattern of the results was rather irregular and did not follow the trends of the reflection spectra. The vertical height graphs demonstrating this can be seen in Appendices 5 and 6. The clear deviation from expected values is seen in the growth of the specimens under orange light in Appendix 5. There are several explanations possible for this event, but due to the sizes of the irregularities in this trial it is likely that a good portion of results were simply errors.

Nonetheless it is worth mentioning that in this trial, it appeared a general trend that the chlorophylls present in the *Helianthus annus* were not as adept at capturing and using shorter wavelengths of visible light (blue), as they were at capturing the longer wavelengths in the visible spectrum such as red. This is contradictory of the generic action spectra and is quite an interesting observation.

In the second trial, it was possible to see the pattern of the action, and reflection spectra more clearly. However, before considering the effects of the different colors of light, one must remember that the main assumption linking the variables of growth and color of light in this investigation is photosynthesis. Since the *Helianthus annus* is a fast growing plant, one can assume that its growth is directly related to its photosynthetic action, since this is the plants' only variable source of energy. Since all other environmental variables were constant, it is assumed that any signs of lack of light were directly related to and caused by, the photosynthetic action occurring within the sunflower specimen, and the photosynthetic pigments it contains.

3.2 Vertical Growth

In the first trial of this investigation, vertical growth of the specimens of *Helianthus annus* under the different colors of light was measured in response to time. The full results for this trial can be viewed in Appendix 1, and the processed average height results for each color in Appendix 2. Upon conclusion of this trial, it was evident that the varying sizes of cotyledons in the separate plants were a strong indicator of the specimens' responses to light. So, in the second trial, cotyledon size was measured in relation to time along with vertical growth.

The full bulk values for the vertical growth in this second trial can be seen in Appendix 3. When considering these values, it is quite ungainly to compare three separate sets of values from each color of light, a total of eighteen sets of values. Hence, average values for each of the separate colors were obtained as can be seen in Table 3.4, thus allowing for a simpler analysis of the data.

Table 3.4

		Time (Days)													
	Color of Light	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
Growth (cm)	**Full Spectrum**	0	0	0.5	3.6	5.6	7.9	9.6	10.9	12.3	12.8	13.5	13.9	14.3	14.7
	Blue	0	0.5	1.2	4.7	6.8	9.2	10.9	11.8	13.6	14.2	14.8	15.0	15.3	15.9
	Green	0	0.9	2.3	5.7	8.1	10.9	13.1	13.7	14.6	15.4	16.1	16.4	17.0	17.5
	Yellow	0	2.2	4.0	5.7	7.9	10.0	11.0	12.0	13.0	14.0	14.6	14.9	15.3	15.7
	Orange	0	0.4	2.4	3.4	6.0	7.9	8.9	11.5	12.1	12.8	13.5	13.9	14.5	14.9
	Red	0	1.7	3.4	5.3	7.9	9.3	10.5	12.0	12.7	13.4	13.7	14.0	14.4	14.6

The final values of average vertical growth in each color of light from Table 3.4 are compared in the following bar graph.

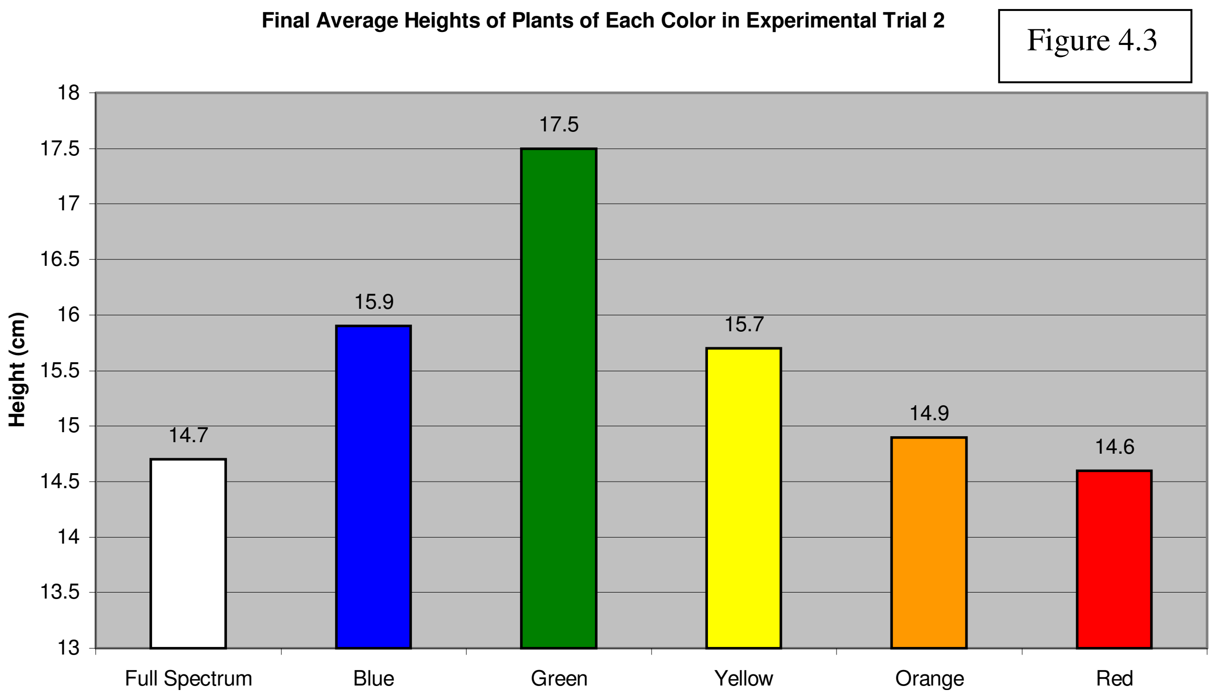

Figure 4.3

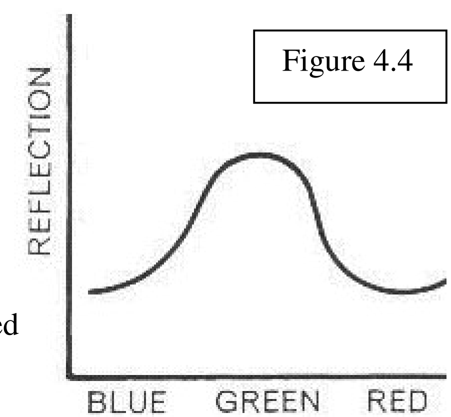

Figure 4.4

Due to the knowledge of the reflection spectra shown in Figure 4.4[5], the green light will be almost entirely useless for photosynthesis because most of the photosynthetic pigments in the plant are green (all chlorophylls) and thus would reflect green light. Hence, it is entirely justifiable that in the results, green was the greatest plant in height, and experienced the most pronounced lack of light. Likewise, the yellow light caused similar effects. As shown in Figure 1.1, the action spectra for the wavelengths of yellow show that there is almost no photosynthetic activity, so the height of the plants is also not unexpected. The blue light was again surprisingly inactive in this trial. This repeated unhealthy response of the *Helianthus annus* to the blue light suggests that the plant cannot effectively capture or process its wavelengths.

Considering Figure 4.3, it can be seen that the final values shown in Table 3.4 do not show the full story. So, to obtain a full perspective on the duration of the experiment, the

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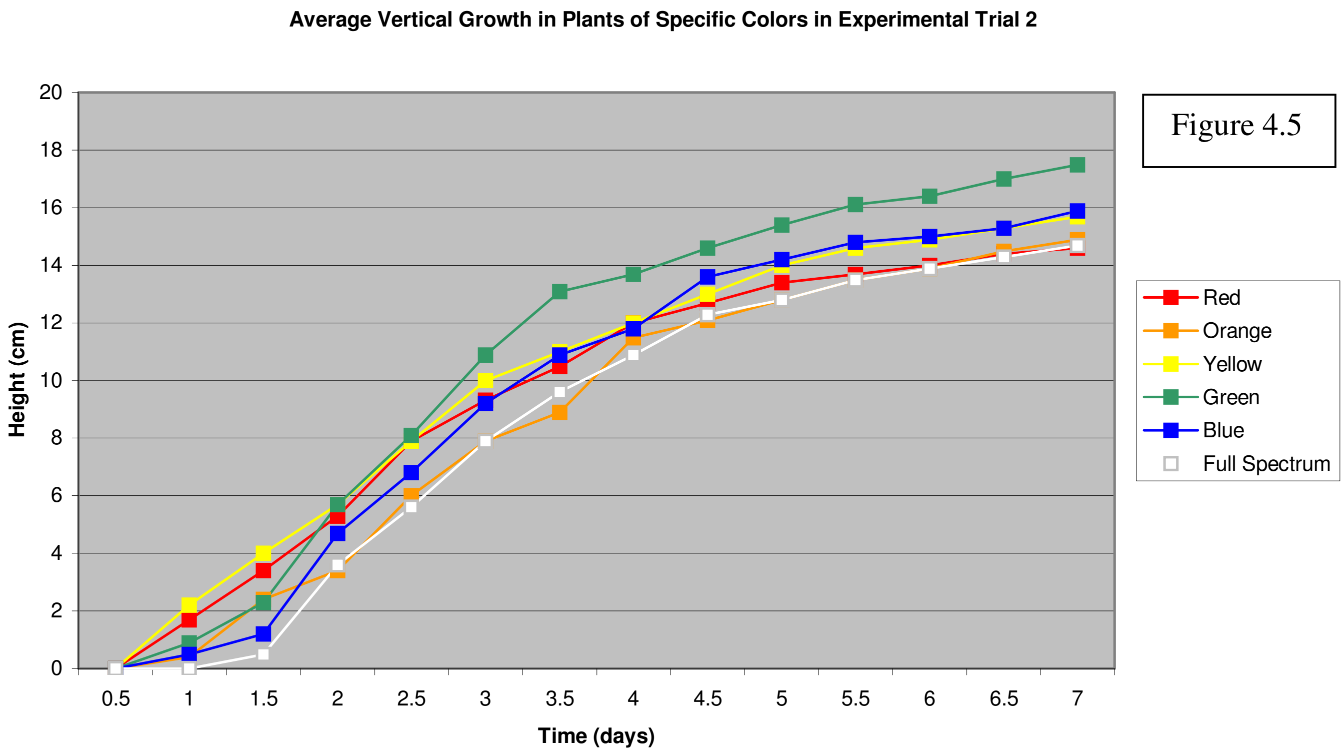
[5] Unknown. *Research Question/Hypothesis*. http://csc.gallaudet.edu/soarhigh/Leaves/gle.html. 10.06.2003

entire vertical growth of the specimens in each color of light in relation to time should be shown as in Figure 4.5 below.



The specimens under the blue light appear produce healthy growth until halfway through the experiment where they join with the yellow light with unhealthier growth. This continues to suggest along with the results from the first trial, the photosynthetic inactivity of the blue light for the *Helianthus annus*. This could have resulted from several causes. Firstly, it could be that the photosynthetic pigments in the *Helianthus annus* do not capture shorter wavelengths such as blue light as effectively as longer wavelengths in the visible spectrum. This would be a reasonable claim since the red and orange colors of light (longer wavelengths) appear to invoke a positive photosynthetic reaction in the growth of the *Helianthus annus*. The other cause could be, that there is a low quantity of accessory pigments (carotenoids) present in the *Helianthus annus*. This is possible since, in the only wavelengths of light where the carotenoids operate (blue and violet), there appears to be abnormally low photosynthetic activity. Then, in the wavelengths where reflection would occur due to the color of the accessory pigments[6] (longer wavelengths of red and orange) there is quite high photosynthetic activity.

So it seems that the longer wavelengths of red and orange were successively adept in causing healthy reactions in their specific specimens. This suggests that the absorption spectra for the *Helianthus annus* would show considerably higher maxima for activity in the longer wavelengths of light in relation to shorter wavelengths than most plants in general as represented by Figure 1.1. However, one must clearly note that in this investigation, only 3 plants were used to gather results from each color of light. This means that well based conclusions cannot be made because in principle, 100 plants are required under each color of light. This was not possible due to lack of resources, but this investigation should be repeated with an appropriate number of plant specimens so that results obtained can provide justifiable conclusions.

The full spectrum light, which should have had the lowest height, did not, but rather, red light did. This seems in theory highly unlikely since a specific wavelength in a plant's photosynthetic range cannot cause more photosynthetic action than the plant's entire action spectra. Also, it can be seen from the graph that until day 6.0, the full spectrum light was the smallest in height and it was growing at a constant rate. Then, after day 6.5 and 7.0, the plants under red light seemed to significantly slow down growth and attain a smaller average height than the full spectrum light specimens. From these observations one can deduce that the average red light plant height was only smaller in size than the full spectrum light because of some irregularity in growth to the fault of the seed or some other error causing the plants to grow slower than they would normally. A possible irregularity could have been the special bulb obtained for the full spectrum light. This bulb may simply not have been as powerful in relation to the red bulb as it should normally have been.

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[6] Coder, K. *Fall Color Tree Pigments*. http://www.forestry.uga.edu/warnell/service/library/for97-030/. 09.06.2003

3.3 Cotyledon Growth

Since the values obtained for cotyledon growth are so simple, and generally very similar, just the daily average cotyledon lengths for each light color are given rather than readings for every specimen. In the instance of a plant not emerging from the soil whilst others had already arisen, the missing plant was omitted from the average.

Table 3.5

		Time (Days)													
	Color of Light	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
Growth (cm)	**Full Spectrum**	0	0	0	0.8	0.9	1.0	1.2	1.4	1.5	1.5	1.6	1.7	1.9	2.0
	Blue	0	0.8	0.8	0.8	1.0	1.1	1.2	1.2	1.3	1.3	1.5	1.5	1.6	1.6
	Green	0	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.1	1.2
	Yellow	0	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.5
	Orange	0	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6
	Red	0	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.5

In order to obtain final insight to the effects of the different colors of light on the growth of the plants in question, it is necessary to consider the measures from Table 3.5 and consider them in relation to the vertical growth values to make final conjectures on the light dependent growth of the *Helianthus annus*. The best representation of the cotyledon measurements can be shown in Figure 4.6.

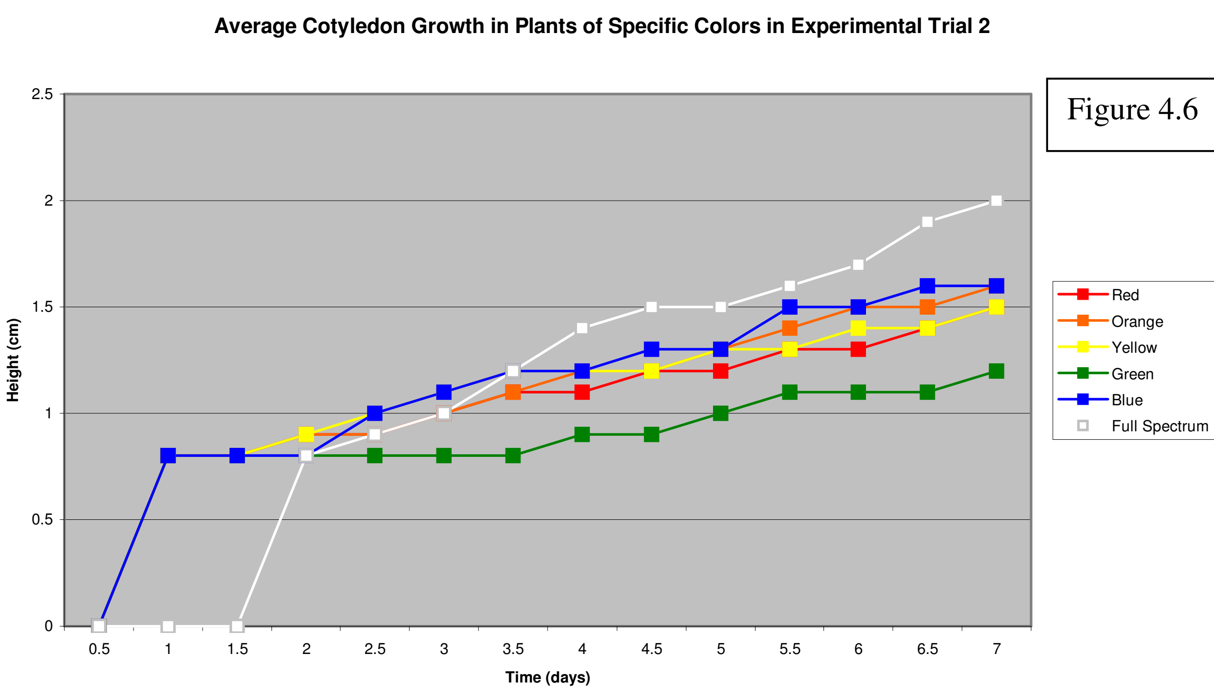

Figure 4.6

What can be noticed from this graph right away is the clear lead of the full spectrum light in cotyledon size and the small size of the cotyledons in green light. These are unarguable and do not require explanation. The rest of the colors fall in between these two and seem randomly mixed within a very small margin of each other. It is likely that this margin is too small to definitely make conclusions. However, although blue light did have unhealthy height values throughout both trials, it appeared to show some promise in the relative size of its cotyledons. The cotyledons appear to be just slightly larger than the rest of the intermediate colors throughout the experiment. However, one must again note that fully justified conclusions cannot be made with these results since the principle number of 100 specimens per color of light was not used.

3.4 Unique Growth

Although the presence of several different factors of unique growth does not directly pertain to the research question, it does demonstrate how the different colors of light affected the general healthy growth of the plants and can be used to support the previous results and show improvements possible for further investigations.

Firstly, by the end of both trials, each specimen tilted at angles of over 45 degrees, and possessed little stem rigidity; very uncharacteristic of typical *Helianthus annus* growth. Also, in the second trial, the cotyledons of the specimens under green light, turned yellow.

The tipping of the plants did not happen specifically to any specimens and therefore must have resulted from general lack of light among all the individuals. This means that in further investigations, the apparatus needs stronger light bulbs greater than 25 watts to provide sufficient light to the sunflower specimens, which need strong luminous power anyway and did not receive it even under the full spectrum light. The same concept applies for cotyledons under green light turning yellow. This could result from either lack of light or lack of minerals[7] (nitrogen and sulphur primarily), and since the latter could not have occurred, the cause was insufficient luminous power.

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[7] Unknown. *Sunflower: Nutrient Imbalance*. http://monsantoindia.com/asp/facts/sunflower/advsflwrfctrnutr.asp. 09.06.2003

4. Conclusion

Looking back on the results obtained from the trials one and two of this experiment, and the different explored possibilities of how the different colors of light used in the experiment affected the growth of the plants in the discussion, it is possible to draw several conclusions and make final statements as to how these factors corresponded.

Generally, when considering the photosynthetic action spectra (Figure 1.1), it is assumed that the smallest wavelengths of visible light (purple and blue) will invoke the most activity, then will follow the longest wavelengths of visible light (red and orange). In the rear will be the mid-wavelengths of yellow and green, which produce very little photosynthetic activity. When considering the results obtained in two trials for the *Helianthus annus* sunflower, this all was not the case. The longer wavelengths were most active, then followed the shorter wavelengths. The mid-wavelengths of colors yellow and green still naturally brought up the rear.

The reasons for the normally photosynthetically strong blue being undermined by the colors red and orange seem to result from basic light gathering properties of the photosynthetic pigments within the *Helianthus annus*. It seems most likely that the pigments within the plant, as all of them can trap the shorter wavelengths of light, are simply not as adept at capturing the lower light wavelengths, as they are the longer wavelengths. This is why the colors of light such as red and orange invoked healthier growth in the *Helianthus annus* than the blue light. The fact may be as well that there are less accessory pigments such as carotenoids present to capture the blue light and lower wavelengths, but there is no strong support in the obtained results to back up such a precise claim.

The yellow and green light, as predicted caused the unhealthiest growth, and thereby followed their set path in the action spectra. This meant that the *Helianthus annus* like all other plants did not respond well to green or yellow light due to the fact that the light cannot be absorbed by the photosynthetic pigments in the plant because it is reflected since most of the pigments in the plant’s chloroplasts are green.

The control light variable, or the full spectrum light turned out as predicted and produced the healthiest *Helianthus annus* specimens. This was repeatedly shown in the low heights of its seedlings, the sizes of their cotyledons, and the fact that they began to tip as a result of lack of light a few days after the specimens in the other colors of light did.

This investigation should be repeated and continued but with several improvements to the apparatus, and the method. Most importantly, the light bulbs should be more powerful since the tested 25 watts was insufficient, and the method should be altered to include the measurement of the length of the cotyledons since this was an essential variable in observing healthy growth in the *Helianthus annus*.

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6. Appendices

Appendix 1

		Time (Days)													
	Specimen	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
Growth (cm)	**Red 1**	0	0	0	0	1.1	2.8	7.0	8.5	9.3	9.9	10.1	10.3	11.3	12.8
	Red 2	0	0	0	0	0.6	4.5	6.3	7.8	9.0	10.3	11.5	12.1	12.3	14.3
	Red 3	0	0	0	0	0	0	0	0	0	2.5	4.8	6.0	6.5	10.0
	Orange 1	0	0	0	1.1	3.3	5.7	8.5	11.3	12.5	14.5	15.5	17.8	18.8	20.1
	Orange 2	0	0	0	0	0	3.0	5.5	7.8	9.3	11.8	13.3	14.0	15.3	17.0
	Orange 3	0	0	0	0	0	0	0	0	0	1.5	2.0	2.8	3.0	4.8
	Yellow 1	0	0	0	0	0.9	3.8	5.8	7.3	9.8	10.8	13.0	13.5	14.3	14.5
	Yellow 2	0	0	0	0.1	1.9	4.0	6.3	7.8	10.0	11.3	13.0	14.0	15.3	15.8
	Yellow 3	0	0	0.2	1	5.0	7.5	10.5	12.0	12.8	14.3	14.8	16.3	16.0	16.5
	Green 1	0	0	0	0	0	0	1.1	3.8	5.5	7.0	10.3	12.8	15.5	15.8
	Green 2	0	0	0	0.1	2.3	4.5	6.8	8.8	9.8	11.5	12.5	12.8	13.1	15.0
	Green 3	0	0	0	0	0.1	2.1	4.0	6.3	8.8	11.0	12.8	15.3	16.1	16.8
	Blue 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Blue 2	0	0	0.1	2.2	3.0	5.3	6.5	8.3	9.5	10.5	10.8	11.3	12.5	13.6
	Blue 3	0	0	0	2.8	5.0	6.3	10.0	11.3	12.8	14.0	15.5	16.5	17.8	18.5
	Full Spectrum 1	0	0	0	0	0	0.1	0.3	2.5	4.8	7.0	9.5	10.8	12.8	13.5
	Full Spectrum 2	0	0	0	0	0	0.2	2.5	4.3	5.5	8.0	10.0	10.3	13.5	14.7
	Full Spectrum 3	0	0	0	0	0.2	2.8	5.0	7.0	8.8	10.5	10.8	11.8	12.5	13.4

Appendix 2

When calculating these averages, the sets of values for sunflower plants that had not emerged by a time of 3.5 days (halfway through the experiment) were omitted due to the overly large discrepancy from the other values they would produce.

		Time (Days)													
	Color of Light	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
Growth (cm)	**Full Spectrum**	0	0	0	0	0.1	1.0	2.6	4.6	6.4	8.5	10.1	11.0	12.9	13.8
	Blue	0	0	0	2.5	4.0	5.8	8.3	10.3	11.2	12.3	13.2	13.9	14.9	15.8
	Green	0	0	0	0	0.8	2.9	4.0	6.3	8.0	9.8	11.9	13.6	15.0	15.9
	Yellow	0	0	0.1	0.4	2.6	5.1	7.5	9.0	10.9	12.1	13.6	14.6	15.2	15.6
	Orange	0	0	0	0.6	1.7	4.4	7.0	9.6	10.9	13.2	14.4	15.9	17.0	18.6
	Red	0	0	0	0	0.9	3.7	6.7	8.2	9.2	10.1	10.8	11.2	11.8	13.6

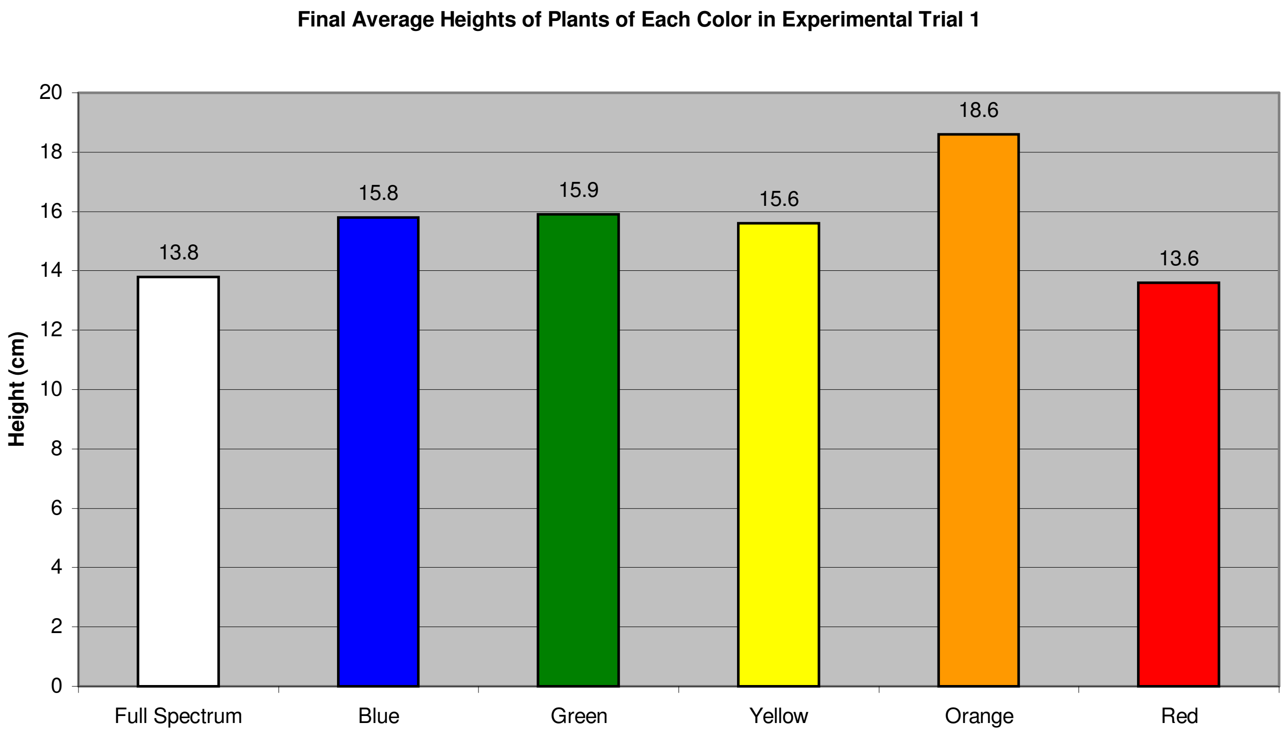
Appendix 3

		Time (Days)													
	Specimen	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
Growth (cm)	**Red 1**	0	2.3	3.5	5.0	7.8	9.3	10.8	12.3	13.0	13.8	14.0	14.1	14.8	15.0
	Red 2	0	2.5	4.0	5.5	8.0	9.5	10.5	11.8	12.1	12.8	13.3	13.5	13.6	13.8
	Red 3	0	0.3	2.8	5.3	7.8	9.0	10.3	11.8	13.0	13.5	13.9	14.4	14.7	15.1
	Orange 1	0	0.3	2.8	3.8	5.8	7.5	8.8	11.5	11.8	12.3	12.9	13.5	13.6	13.8
	Orange 2	0	1.0	3.0	3.4	7.3	9.3	10.3	12.8	13.1	14.0	14.5	15.0	15.3	15.6
	Orange 3	0	0	1.5	3.0	4.8	7.0	7.5	10.3	11.3	12.0	13.0	13.3	14.5	15.2
	Yellow 1	0	2.3	4.0	6.3	8.5	10.8	12.0	13.0	13.5	14.8	15.1	15.3	15.6	15.9
	Yellow 2	0	2	4.0	5.3	8.0	9.8	10.5	11.8	13.0	13.5	14.3	14.8	15.4	16.0
	Yellow 3	0	2.3	4.0	5.5	7.3	9.3	10.5	11.3	12.5	13.8	14.3	14.5	15.0	15.2
	Green 1	0	0	1.0	5.7	8.5	11.8	13.8	14.0	15.5	16.0	16.6	16.7	17.3	17.9
	Green 2	0	0	2.5	5.3	7.0	9.5	12.0	13.0	13.6	14.8	15.5	15.8	16.3	16.7
	Green 3	0	2.8	3.3	6.0	8.8	11.5	13.5	14.0	14.6	15.5	16.2	16.7	17.4	17.8
	Blue 1	0	1.5	3.7	7.0	8.5	11.2	13.5	14.5	14.8	15	15.3	15.5	15.7	16.1
	Blue 2	0	0	0	3.8	7.0	9.0	10.0	10.2	13.2	14.0	14.5	14.9	15.1	15.9
	Blue 3	0	0	0	3.3	5.0	7.5	9.3	10.8	12.8	13.5	14.5	14.7	15.0	15.6
	Full Spectrum 1	0	0	1.0	4.8	6.8	8.8	10.0	11.8	12.5	13	13.3	14.0	14.2	14.5
	Full Spectrum 2	0	0	0.5	3.3	5.8	7.5	9.5	10.5	12.5	12.8	13.5	13.7	14.3	14.8
	Full Spectrum 3	0	0	0	2.8	4.2	7.5	9.2	10.5	12.0	12.5	13.7	14.1	14.5	14.7

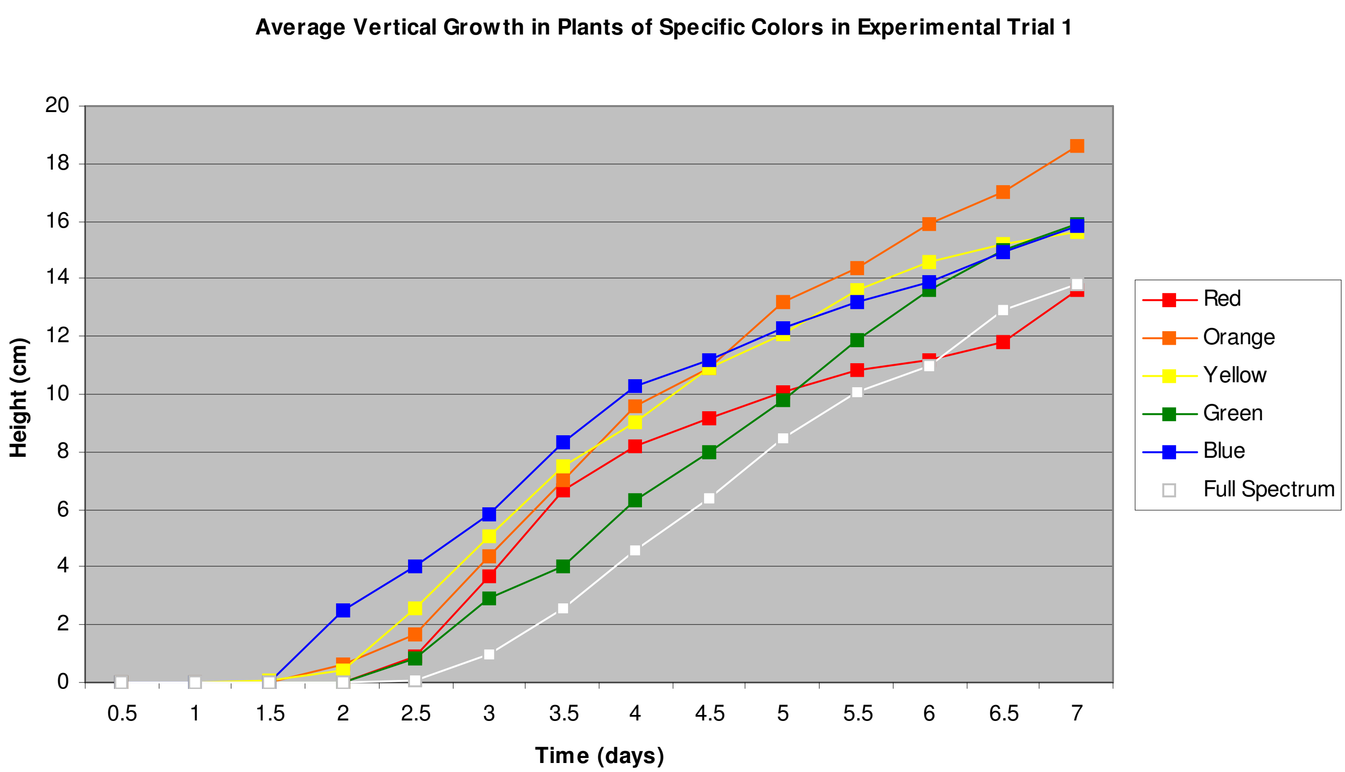
Appendix 4

Class of pigment with examples	Color	Distribution
Chlorophylls		
chlorophyll a	yellow-green	All photosynthetic organisms except some photosynthetic bacteria
chlorophyll b	blue-green	Higher plants and green algae
chlorophyll c	green	Brown algae, and a few unicellular algae including diatoms
chlorophyll d	green	Some red algae
bacteriochlorophylls a-d	pale blue	Photosynthetic bacteria
Carotenoids carotenes and xanthophylls		
Carotenes		
beta-carotene	orange	All photosynthetic organisms except photosynthetic bacteria
Xanthophylls (carotenols)		
Great variety	all yellow	Fucoxanthin helps give brown algae their color. It has a very broad absorption spectrum.

Appendix 5



Appendix 6



Appendix 7

This following is a photo of the constructed apparatus.