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The Radish Seedling Hypothesis

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Nearly all plants need light to survive; however, what about germination of seeds? Experience shows that many introductory biology students falsely assume a seed will not sprout without a source of light. This laboratory uses radish seed germination to teach students about the scientific method, development of good hypotheses, how to test a hypothesis, and what conclusions can be made from experiments. The laboratory is inexpensive, very simple to set up, and allows a student to learn many skills they will need as a biologist.

Keywords: germination, hypothesis, experimental design, lab report

Introduction

Many undergraduate students in introductory biology courses have not learned how to perform the scientific method. We addressed this problem by exposing students to experimental design during their first laboratory as an introductory biology student. This is a minimalistic laboratory project designed to provoke students to think about design and outcomes. This lab provides a framework to discuss important concepts such as sources and types of error, Occam's Razor, variables, controlled experiments, sample size, representative samples, bias, placebo, and many more.

Developing a Hypothesis

Many undergraduate students in introductory biochemistry courses define a hypothesis as an educated guess. This laboratory is designed to help them form a hypothesis based on observations, inductive reasoning, and prior knowledge. The laboratory is very simple to set up and implement. Approximately four days before the laboratory session, students are introduced to the concept of plant growth. Students are asked to name all of the factors that plants require for growth. After reviewing the list, we agree on the topic of light. Each student is asked to create a hypothesis concerning the germination of seeds and their growth in the presence or absence of light. This hypothesis is generated only from prior knowledge. Many students will choose a hypothesis along the lines of "the seeds placed in the light will grow better," or "the radish plants in the light will be healthier." These vague and non-quantifiable hypotheses will be useful for later discussion.

Setting up the Experiment

Students are instructed to "plant" 10 radish seeds on two separate petri dishes. Each dish will have an identical piece of filter paper soaked with an identical amount of water. One dish will be placed in a dark cabinet for 3-4 days, the other under a set of grow lights for 24-hour illumination (Figure 1). This is generally done outside of class and takes the students about 10 minutes to set up. This procedure allows each set of students to work with their own experiment, instead of one set up by the instructor.

The laboratory should have a location where trays with plates of radish seeds can be placed in constant illumination, and a location where plates can be placed in constant darkness. Either a greenhouse, or a rack of fluorescent lights can be used for the light condition. A cabinet that remains closed, or a sealed box can be used for the dark condition. It is good practice to have the temperature equivalent in both locations.

Collecting the Results

On lab day, students will be instructed to collect any type of data that would help them support or refute their hypothesis. Sample setup and results are shown in Figure 2. Before students begin to collect data, we discuss the concepts of bias, sample size, and experimental error. Students are told what materials and instruments are available, and are given time to measure, weigh, sketch, describe, and analyze their plants. Once the students collect data, the entire lab reviews concepts of scientific experimentation. After the students collect the data, each is asked if their hypothesis was supported by the evidence they collected. This provides an opportunity to discuss qualitative data, quantitative data, and falsifiable hypotheses. At this point, the students should rethink their hypothesis in order to make it testable. The end of lab is used to review important concepts related to how scientist perform science, including what science does, what assumptions are made, and the various types of errors and bias that can be introduced into experimental design, data collection, or analysis of results.

Generating a Lab Report

The students will learn to create a lab report in a research article format. Examples of what goes into each section are provided. We spend time talking about tables, graphs, statistics, and how to make conclusions supported by evidence. A sample lab report is provided to the students AFTER they have submitted their reports as a guide for improving future lab reports.

Figure 1. Light apparatus setup for 24-hour illumination of trays containing Petri dishes.

Figure 2. Materials and examples of Petri dish setup.

Student Outline

Objectives
- Students will develop hypotheses and experimental protocols concerning the role of light in radish seed germination.
- Students will compare various physical characteristics of radish seedlings grown under experimental conditions.
- Students will make quantitative and qualitative measurements and draw conclusions from their experimental results.
- Students will learn more about the scientific process, experimental design, interpretation, and strategies for minimizing bias

Introduction
Many types of plants germinate from embryos contained within seeds after a period of dormancy. Plants generally fall into the category of photoautotrophs; organisms that require primarily inorganic nutrients and light to grow. Light provides the energy source driving photosynthesis, the plants source of ATP, and organic compounds. What role does light have in germination? This question can be answered by studying the role of photosynthesis in young plants, such as radish seedlings. In the design of an experiment, every condition that can be altered is considered a variable. The presence or absence of light is a variable in photosynthesis, which means there are two light conditions that we can test. Good experimental design emphasizes having only one, or a few variables that can affect the experimental results. As a first step to determining how light affects the germination of radish seedlings, you should consider all of the variables that can affect plant growth. Because we will focus on the effect of light, we will try to eliminate differences caused by all of these other variables that could affect plant growth.

Methods and Data Collection
Designing a Hypothesis

1. **Develop a hypothesis concerning the effect of light and the germination and growth of radish seeds**. Develop the best one that can be tested given the materials at hand. The supplies available to design your experiment are:
    a. radish seeds
    b. 2 Petri dishes to hold seeds
    c. sterile water, and filter paper to hold the water in the dishes under the seeds (best if saturated but not so wet that seeds float)
    d. a botanical lamp that gives off full spectrum light
    e. a dark cabinet that blocks light
2. **Choosing** the best hypothesis involves reasoning, logic, and knowledge. You will use your previous observations of plants, seeds, and radishes to provide a rationale, or reason for your hypothesis.
3. **Write** your hypothesis and your rationale on a slip of paper and turn it in to your instructor.

4. **Imagine** what kinds of results you might get. **Plan** how you will measure (assess) the outcome of your experiment to **determine** whether your hypothesis is supported or refuted. **Write** this <u>method</u> in your notebook.

Setting Up Your Experiment

5. Four days before your lab, you will need to prepare your radish seed experiment so that it will be ready on your normal scheduled laboratory day.
6. You will label two plastic petri dishes with appropriate information (e.g., names, date, experimental condition, etc.).
7. Place a piece of filter paper on the bottom of each Petri dish.
8. Add 3 mL of sterile water to the filter paper.
9. Add 10 radish seeds, equally spaced, to each Petri dish.
10. Place the lids on the dishes and place a piece of Parafilm around the outside edge of the Petri dish to prevent the water from evaporating.
11. Place one plate under the full-spectrum lights, and one in the dark cabinet.

Data Analysis

12. Each pair of students should **collect** data to discern the differences and similarities between their two groups of radish seeds.

   a. Think of all of the procedures and tools that you can use to collect data.
   b. Consider if seedling should be measured separately, or together for each measurement.
   c. **Transform** the raw data into data that can be interpreted.
13. **Determine** whether your experimental results support or contradict your original hypothesis.
14. **Compare** your results to the rest of the class and **prepare** comments about your findings. Could your results be incorrect? Biased? Include results, conclusions, and a discussion (including speculation about errors and what you would change to have more confidence in your conclusion).

Lab Report

Each student will write a laboratory report in the style of a scientific research article. The format for articles is described below. You may also look at sample articles provided by your instructor.

- Brief introduction: 2-3 paragraphs that includes background and leads into hypothesis.
    - Don't copy from handout, you should design it from text, notes in class/lab, other materials. You must reference sources.
- Statement of hypothesis/purpose: 1 paragraph.
- Rational for hypothesis: Justification of your hypothesis based on information provided in the introduction of your report. 1-2 sentences.
- Material/methods: How would someone repeat this experiment? Write this section a block of text that describes your protocol; however, you should leave out steps which are obvious to the reader.
- Results: The results section is a logical presentation of your observations. These may include graphs, additional tables, photographs, artwork, and text. Be sure to label all results and describe the data. Be sure to provide analysis of data to show trends.
- Discussion: Do not present new data here. This section is for explanation of results including analysis and statement of trends. You should make your interpretation of the data clear to the reader. You may need to reference other sources. You may also offer alternative explanations for your observations. Any sources of error should be mentioned, but you do not need to write human error unless you are confident you did not follow the protocol. In addition, you can suggest additional questions or experiments that logically follow completion of your project.
    - Does your data support your hypothesis?
    - What would be an alternative hypothesis?
    - Describe connections to introduction/field.
    - State any sources of error, unexpected results.
    - Provide future directions for experimenters.
- References: Provide the sources for any information you used in your report.

Materials

Students will work in pairs (the following is for 24 students)

Each pair of students will need the following for day 1:

- Two 100 mm Petri dishes per pair of students (24)
- Filter paper cut in circles that will fit into the bottom of each Petri dish (24)
- 20 radish seeds per pair of students (10 per dish), approximately 250.
- sterile water (about 500 ml)
- transfer pipettes to add water to Petri dishes (about 5 ml per dish)
- Parafilm to seal Petri dishes
- marking pens to label Petri dishes
- Large trays (one for each lab group) to be placed in 24 hours light
- Large trays (one for each lab group) to be placed in 24 hours dark

We will need the following additional items for lab on day 3-4:

- 2 balances for measuring mass
- weighing paper to weigh radish seedlings
- rulers (9 or 10)
- string
- scissors

Notes for the Instructor

This laboratory is focused on teaching students about inquiry of science. Before the lab section meets, students should have developed a hypothesis concerning radish seed germination in the light and dark. The students will also be required to "plant" their seeds 3-4 days before their lab session (depending on scheduling). The lab session focuses on class discussion, lecture, and collecting data. The following is the laboratory outline used by the instructor to guide the students and teach the scientific method and scientific experimentation principles. In addition, the students will submit a lab report as described in the student handout. The sample lab report (Appendix A) is returned with the student's graded report as an example of how to improve future lab reports. It also serves as a rubric for evaluating the student work.

Radish Seed Lab Introduction

Suggestions for introduction to the lab include asking the following questions: What is science? (an *Explanation of phenomena)*. How is scientific inquiry different from other fields of study such as math, history, art, or literature? *(ways of perceiving the world).*

The following quotation may be used to describe the importance of science as part of a broad education:

> Thomas Cech – "study of great books, history, languages, music, and many other non-science fields is likely to hone a scientist's ability to perceive and interpret the natural world. More specifically, in history, literature, and the arts one is presented with diverse, often mutually contradictory "data"—different points of view due to incomplete knowledge or the different backgrounds of those doing the viewing. One learns to distill the critical elements from the irrelevant, synthesize seemingly discordant to observations, and develop a strong argument." (*In essence, scientist need to be able to detect bias and think in new ways)*

How Do We Study Science?

Work through the following concepts with students:

The Scientific Method consists of the following steps:

- Observation of phenomena.
- Development of a hypothesis that is testable and falsifiable.
- Devise an experiment with controls and make a prediction of the outcome of the experiment.
- Test your hypothesis with the experiment.
- Draw conclusions from the experiment.

Walk through concepts of experimentation including the importance of models and feasibility:

- How about an experiment to see how light affects the final height of Sequoias? *(students should guess this is not doable)*
- What is a model? – bridge, airplane, train – be able to perform a test on small, feasible scale.
- For biology, models include *Arabidopsis*, mice, worms, yeast – all better for size, time, and cost.

Next – Set up the Experiment

Ask students: How many variables did we choose? (*one, light*). Ask students: How many variables could we choose? (*many, water, temperature, nutrients…).* Describe control and variable groups.

Ask students: How many seeds do we need?

- Many… Why? (*need representative sample size*)
- *1 is too little, 1000 too much due to time/resources.*
- Picking many allows for representative of population.
- Sample size = n.

We chose one variable – what are the assumptions that we are making? (*That we could generate a hypothesis and test it.)*

How to Test Your Hypothesis…

Ask class what can be done with the tools available: a balance, string, ruler, and their senses… (*Measure, stem, root, both, mass, color, number germinated, thickness)*

Time for Students to Perform the Experiment

Questions to ask while lab is in progress on individual basis:

- Should students weigh each seedling separately or each condition as a group?
- How can one quantify color?
- If there are mass difference, how did these differences arise?
- Does averaging cause information loss?
- Was the amount of water added to each dish constant?
- Is the amount of available water in each dish the same?
- Ask the student what their hypothesis is; if they said "better", ask the student what better means in other words. Is it taller, greener, heavier?
- What physical traits need to be measured to address their hypothesis?

Final Discussion

Ask the students if the hypothesis is supported by the evidence they collected? *Yes or No*

Continue with the following questions and prompts:

- How does light influence the color of the plants?
  - Exposure to light stimulates chlorophyll synthesis resulting in green seedlings.
  - There is a profound difference between light and dark radish groups.
- Were patterns of germination frequency seen?
  - Exposure to light generally decreases percent of germinating seeds.
  - A larger frequency of seeds in the dark condition germinated.
- Any ideas for why dark plants were larger?
  - The seedlings were searching for a source of light.
- Could assumption that light and dark are causative be wrong?
  - There may have been differences in the temperature or availability of water.
  - We need to think critically to come up with an answer, it is not easy to set up a controlled experiment.
- Discussion of causation vs correlation
  - Leaves turn color and fall off trees each autumn as the temperature outside drops for winter.
  - Do any other events reliably occur outdoors each autumn? How about the duration and intensity of sunlight? How do you determine if temperature or light are causative?
- What do we do with the data?
  - Analysis, statistics, graphing.
  - Discuss Mean, median, mode, raw data, standard deviation.
- Why do you think the plants were larger in the dark?
  - Where does the energy come from?
  - Consider other seeds such as peanuts, peas, or rice. We eat these seeds as food because they store energy in the endosperm.
- Are there any difference in mass between the light exposed and dark grown radish seedings?
  - If so, how does this data relate to original hypothesis?
  - What did we mean by grow in the original development of the hypothesis?
  - If the original hypothesis is not supported – do we throw it out?
- Could there be errors in our data collection?
  - Expound / explain types of errors and implications of each:
    - Systematic – all data is biased the same amount. May be corrected.
    - Random error – each data point is inaccurate by a different amount.
- Is everything in our experiment natural?
  - Is natural good?
  - Use example of snake venom, poisonous mushrooms, etc. to dispel belief that natural is always beneficial.
- Describe Occam's Razor to students:
  - William Occam – 14th century English logician and Franciscan friar.
  - Occam's Razor states that when choosing an explanation for a phenomenon, the one with the least number of new inventions is preferable.

    - Occam's Razor is a general rule, it does not always result in the correct explanation.
- Ask students if someone can prove a hypothesis?
    - The answer should be no in the sciences.
    - Instead, the results of an experiment are consistent or not consistent with a hypothesis.
    - There are always more ways to explain a phenomenon; therefore, no one explanation can ever be proven.
- Describe the term theory.
    - In science, a theory is a very well tested hypothesis – it has a different meaning than the popular term theory used to express an untested idea.
    - A theory explains an observation with an explanation with predictions that are consistent with every experimental design tested.
        - Evolution is a fact that allele frequencies have changed in populations over time.
        - Natural Selection – one theory that explains the fact of evolution based on variation in populations, inheritance of traits, and competition among individuals for scarce resources.

Finally, setting up a hypothetical experiment:

- The scenario is that you have a pet store that sells tropical fish. A disease has infected many fish and appears to be spreading. Fortunately, you have heard that there is a new fish medicine that treats this disease. Here is how you set up the experiment:
- You have 10 tanks of 10 fish each.
- First week – no medicine. Results, 5 fish per tank die, or 50% of the population
- Second week – you add the medication to all 10 tanks. Only one fish per tank dies during the second week; Only 20% of the remaining fish.
- You conclude that the medication is effective because the first week 50% of the fish succumbed to the disease, but once the treatment was added, only 20% of the remaining fish died.
- Ask students if this a good experiment? How can if be improved?
    - Start with a control group and an experimental group that are observed simultaneously.
    - Randomly choose fish to be placed in each group.

About the Author

Pliny A. Smith obtained his B.A. in Biology from Grinnell College in 1992 and his Ph.D. from the University of Missouri in 2001. He is an assistant professor in the Biology Department of Dominican University in River Forest, IL. Pliny teaches Developmental Biology, Genetics, Organism Biology, and the Biology of Aging. He uses *C. elegans* both in the classroom as well as to train undergraduates to carry out original research.

Appendix A

Thomas Hunt Morgan

Lab Partner: Linus Pauling

09/04/1914

Include the title, date, and your name and your lab partner(s)'s name

Radish Seed Germination Lab

Introduction:

All organisms must interact with their environment to obtain energy, avoid damage, and reproduce. According to the second law of thermodynamics, both plants and animals require external sources of energy to maintain order and survive[1]. Representatives of some kingdoms, such as animals, obtain energy from organic molecules acquired by consuming other organisms[1]. In contrast, most plants convert solar energy to chemical energy for growth and maintenance of tissues using a process called photosynthesis[1]. While this laboratory focuses on energy and growth, plants are also affected by other environmental variables such as the availability of carbon dioxide, minerals, and water as well as temperature, disease, predation and responses to gravity[2].

An interesting question is whether plants require exogenously supplied energy to germinate and initiate growth. We have chosen the radish seedling as model for plant growth. Radish seedlings have the advantages of being inexpensive, small, and easy to cultivate, but share characteristics with other plant species. Seeds from flower plants, such as the radish[3], consist of an arrested plant embryo and additional tissue called endosperm, which may be starch or lipid rich[1]. Germination is the process of the seed absorbing water, its cells leaving a dormant state, and the tissues expanding to break through the seed coat[1]. While it appears obvious that water is necessary for this process, is the presence of the endogenous stored energy source stored in the endosperm of the seed enough to permit robust growth of the seedling?

Introduction: 3 points

The introduction should start with broad statements about the subject. In a minimum of 2-3 paragraphs, it should focus on providing the information and questions necessary for the reader to understand the problem or "gap of knowledge."

The introduction is not simply a rewritten lab purpose, protocol, or results section.

Be sure to acknowledge any sources that you used in your introduction. Remember the plagiarism policy.

Hints on biological writing:

1) never use direct quotes, you should create your own sentences

2) Writing style matters, if you are not an excellent writer, take your draft to the writing center

3) Do not just fill up a page with random facts, this is the first section your reader will see.

4) Although you perform the experiments with a partner, the lab write-up should be written individually.

Hypothesis:

Radish seeds planted on wet filter paper and exposed to light will germinate and the seedlings will become larger and greener than those from radish seeds planted without exposure to light.

Hypothesis: 2 points

The hypothesis must be an explicit statement that makes a prediction that is testable and falsifiable. (I am accepting less-than-perfect hypotheses for the radish seed lab)

Justification/Rationale:

Radish seeds are embryonic plants, which require sunlight in order to obtain energy using photosynthesis. Without sunlight, the radish seeds will lack enough chemical energy to build new tissue such as stem, root, and leaf.

Justification: 1 point

This may be included as part of the hypothesis section or the introduction

Materials and Methods:

The protocol described in the handout "Radish Seed Germination" was performed as written with the following exceptions/additions:

- Two groups Petri dishes were prepared by placing a single piece of filter paper in the bottom and adding sterile water until the paper was thoroughly moistened. Ten (10) radish seeds were placed in each dish, which was labeled and sealed with parafilm. One dish was placed under full-spectrum lighting while the other placed in a dark cabinet. After three (3) days, the plates were removed and the radish seedlings analyzed.
- Measurements of mass were obtained by placing each radish seed or seedling on a Mettler Toledo balance and recording the mass in mg.
- Measurements of root length were obtained by allowing a short piece of string to conform to the general shape of the root from the tip to the pigmented, non-root haired portion of the stem. The string was then pulled taunt and measured with a metric ruler.
- Measurements of total length were obtained with string as above, but measuring from the attachment point of the leaves to the root tip.
- Measurements of color were observed by eye and described as yellow or green.

Materials and Methods: 1 point

The protocol from the lab handout does not need to be copied, but any modifications or additions do need to be mentioned in this section. Notice that the *Radish Seed Germination* lab handout did not provide instructions for the full experiment setup, nor did it provide the methods for analyzing the radish seedlings. By using this section and the lab handout, anyone should be able to repeat your experiment entirely.

Results:

Table 1. Description of "Dark" Radish Characteristics

Seed	Germination	Color	Mass (mg)	Root Length (mm)	Total Length (mm)
1	Yes	Yellow	110	28	40
2	Yes	Yellow	50	24	38
3	Yes	Yellow	90	14	24
4	Yes	Yellow	40	31	44
5	Yes	Yellow	80	36	50
6	Yes	Yellow	40	14	22
7	Yes	Yellow	70	31	43
8	Yes	Yellow	80	30	38
9	Yes	Yellow	80	19	32
10	Yes	Yellow	90	24	39
Mean			**73**	**33**	**37**

Results: 6 points

Should include appropriately formatted data including tables, charts or graphs, sketches, photographs, and observations. Data should be analyzed in ways not limited to providing averages (means), medians, statistics (such as p values), and labels/measurements of sketches and photographs. Not all lab reports will require all types of data presentation and analysis.

Note: do not provide explanations in the results section; save explanations for the discussion section

For this lab, the results section should contain: a table or tables describing color, mass, and length of radish seedlings incubated in light and dark; the mean (average) mass and height of each; and comparison of the two groups. Additional sketches, descriptive terms, or comparisons are needed for full credit.

Table 2. Description of "Light" Radish Characteristics

Seed	Germination	Color	Mass (mg)	Root Length (mm)	Total Length (mm)
1	Yes	Green	70	18	30
2	Yes	Green	50	14	20
3	Yes	Green	60	14	24
4	Yes	Green	40	11	18
5	Yes	Green	70	16	28
6	Yes	Green	30	11	19
7	Yes	Green	40	18	25
8	Yes	Green	50	16	25
9	No	n.a.	n.a.	n.a.	n.a.
10	No	n.a.	n.a.	n.a.	n.a.
Mean			**51**	**15**	**24**

Light Dark

Figure 1. Sketch of "average plant."

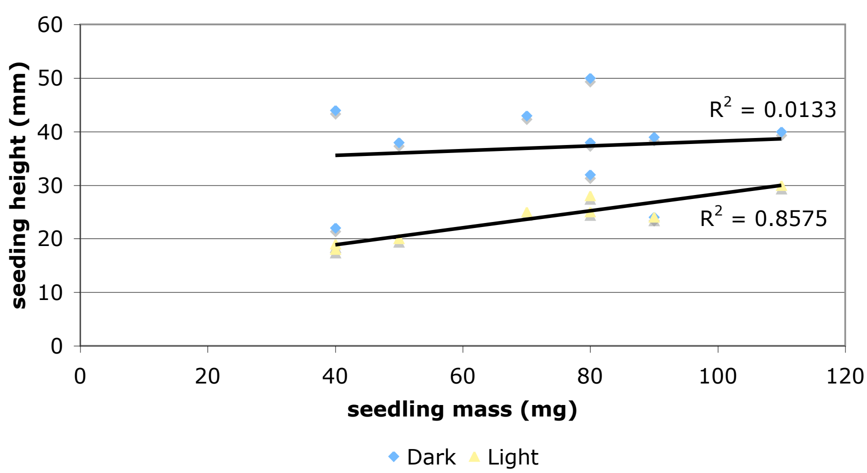

Figure 2. Scatter Plot Comparing Size of Light and Dark Radish Seedlings.

Differences between the control and experimental radish seed groups included the following observations: Only 80% of radish seed germinated in the light while all ten radish seeds planted and incubated in the dark germinated. All radish plans that did germinate in the light had a dark green pigment color while all radish plants in the dark had a pale yellow pigmentation of the leaves. In addition, plants grown with light produced red stems compared to white stems in dark plants. It also appeared that plants grown in the light had more root fuzz than those grown in the dark, but we did not have an accurate method to measure root fuzz (Figure 1).

Plants grown in the dark were 30% more massive, had 55% longer roots, and were 35% taller on average than plants incubated in the light (Tables 1 and 2). In addition, a scatter plot comparing mass to height of seeds that germinated and grew in the dark and light shows a more consistent mass/height ratio for those grown in the light (R2 = .86) than those grown in dark (R2 = .01) (Figure 2).

Discussion:

Discussion: 4 points

The discussion section should explicitly state if the hypothesis was supported or refuted by the data obtained in the experiments. An alternative hypothesis should be proposed if the original hypothesis is not supported. The alternative hypothesis should be justified using 1) the data obtained in this experiment, 2) outside references.

The discussion should also attempt to explain any unpredicted results or observations. Sources of error should be disclosed to the reader.

The discussion also should connect this result to the field as a whole, *i.e.* farm workers should ensure seeds are buried for better crop germination and survival; an underground location without light ensures more consistent moisture for a seedling to use during growth; etc.

Finally, the discussion should mention future experiments that should be conducted based upon your work.

The hypothesis that seeds placed in constant light would become larger than those grown without light was refuted by the data obtained in the experiments described. An alternative hypothesis that fits the data is that seeds that do not receive any light will become taller and more massive than those grown with constant light. This is supported by the average 30-35% increase in size of the radish seedling grown without light in the current experiments (Tables 1 and 2).

Explanations for these results include the stored source of energy and organic molecules provided by the endosperm tissue of the seed, evolutionary advantages of preventing germination and growth of seeds exposed to sunlight, and unaccounted variables in the laboratory protocol.

Plants that reproduce by using seeds provide the dormant embryonic plant with a source of nutrients called the endosperm[1]. Not all plants produce seeds; therefore, the results of this laboratory may not be applicable to mosses, ferns, and other non-seed bearing phyla[3]. The endosperm provides all of the necessary structural and energy containing macromolecules necessary for the average plant embryo's root and stem to grow large enough to anchor the plant and reach a light source[1]. Because most of the mass of the seedling consists of water absorbed from its surrounding, the plant can grow quite large without initiating photosynthesis[2].

Natural selection has also played a role in seedling development. A seed that germinates readily in light risks the possibility that it will not be anchored firmly in soil and that it will be unable to acquire a constant source of water. Examples of misappropriate germination would include germination in puddles, on rock surfaces, or above ground. Because all of these situations lower the chance of survival of the seedling, those plants providing alleles preventing misappropriate germination would be more likely to have successful offspring.

Other explanations include variables that remained uncontrolled during the Radish Seed experiments. These include, but are not limited to, temperature differences between groups, variation in the amount of water added to each Petri dish, and differences in the arrangement of seeds on the moistened filter paper. Temperature differences did occur, primarily because of the florescent light fixtures, which produce small amounts of heat. In some cases, the heat was sufficient to cause increased evaporation of the water from the filter paper, effectively drying the seeds and seedlings. The amount of water added to each plate was not carefully measured;

therefore, light plates may have received more or less water, which could affect growth rates as well. Finally, our group noticed that the seedling grown in the light were closer together and more tangled than those we incubated in the light. The proximity of the seedlings may have interfered with their ability to obtain water, nutrients, or gasses necessary for growth. It is interesting that plants grown in the light are more consistent in size when compared to those grown in the dark (Figure 2)

This work shows that the method used to plant seeds does affect plant growth and possibly success of reproduction. Those persons working in the agriculture industry should ensure that radish seeds are planted under soil for more robust root and stem growth. However, our experiments do not provide the optimum amount of coverage, or darkness required for ideal radish seedling growth. Future experiments could include testing different time periods of incubation in the dark to mimic the depth of planting. Even more convincing would be experiments using different depths of soil and the success of radish plants maturing to reproductive plants.

Spelling, Grammar, Style, References: 3 points

Efforts should be made to use correct, scientific terminology, to write well, and to avoid spelling errors.

References

1. Campbell et al, *Biology Concepts & Connections*, Sixth Edition (2009)
2. Lecture Notes from Biology 120 Class or Lab
3. Laboratory handout “Radish Seed Germination”

Mission, Review Process & Disclaimer

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