Hairy's Inheritance: Investigating Variation, Selection, and Evolution with Wisconsin Fast Plants

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Introduction

Since the dawn of agriculture, humans have invested considerable effort in the domestication of plants by selecting and breeding for agricultural production and aesthetic value. Most of the vegetables available from the local grocery store today bear little resemblance to their wild ancestors. From hybrid disease-resistant vegetable crops to ornamental orchids, humans have altered crop species over thousands of years by selecting desirable traits through the generations.

Excellent examples of vegetable breeding can be seen in the crucifer family. Worldwide, the brassicas (a genus of the crucifer or mustard family) have great economic and commercial value and play an important role in nourishing the world's population. Brassicas range from nutritious vegetables, mustards, and oil-producing canola to animal fodders, ornamentals, and noxious, persistent weeds.

Brassica oleracea is among several species of Brassica that have been significantly altered by domestication. From a common ancestor of wild cabbage that resembles kale, early farmers in various parts of Europe selected individual plants from local populations of *Brassica oleracea* that were more edible, succulent, or storable over winter. The resulting plants had a variety of forms and served as parents for subsequent generations. Today, we see their distant progeny in the grocery store as familiar vegetables:

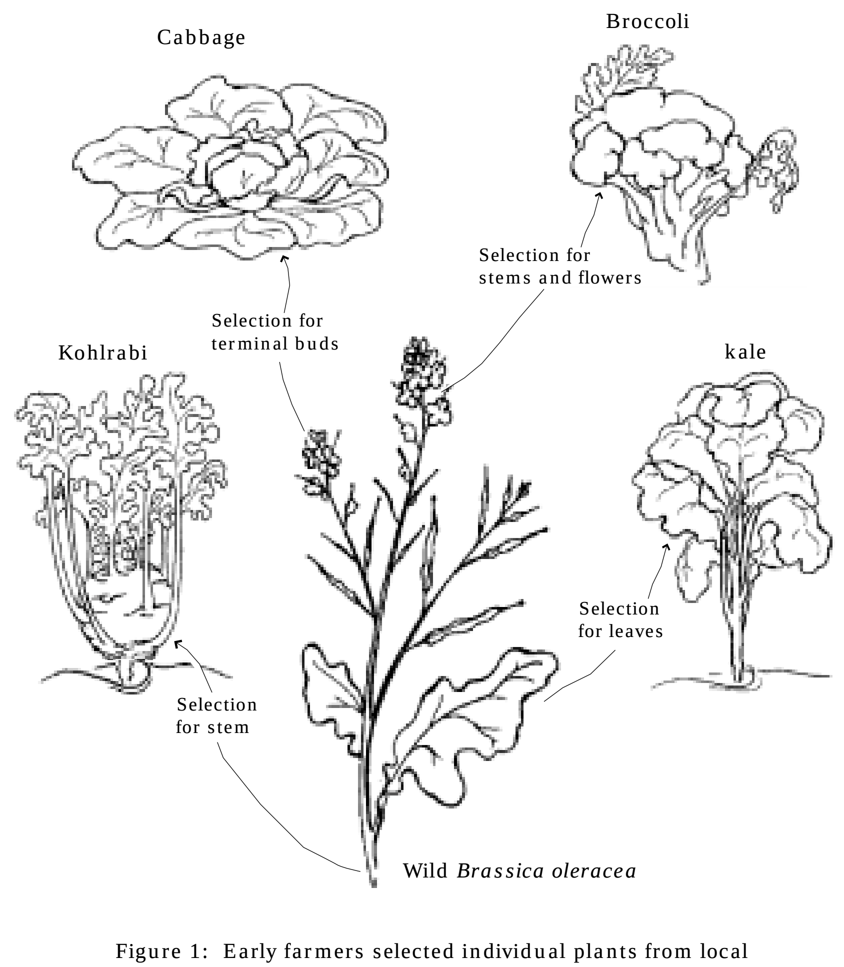

Figure 1: Early farmers selected individual plants from local populations of *Brassica oleracea* for large leaves, stems, buds and flowers. Today, we see the progeny of these selections as kale, broccoli, cabbage, and kohlrabi.

- Broccoli: selected for large, succulent stems and flowers
- Cabbage: selected for large terminal buds
- Kale: selected for large leaves
- Kohlrabi: selected for enlarged, globular stems

Another example of selective breeding, in a Brassica species, is the Wisconsin Fast Plants, *Brassica rapa*. Fast Plants are close relatives (same species) of turnips, Chinese cabbage, and pak choi. However, rather than producing a swollen root like a turnip or an enlarged terminal bud like Chinese cabbage, Fast Plants have been selected for other desirable traits such as:

- Short life cycle with rapid flowering time and seed maturation
- Petite plant form
- Ability to grow under continuous fluorescent light
- Ability to produce large amounts of seed
- Absence of seed dormancy

Breeding for these traits resulted in rapid-cycling *Brassica rapa* stocks with a life cycle of 35-40 days which were named Wisconsin Fast Plants (Figure 2). Because of their short life cycle, Fast Plants are well-suited for both plant research and classroom education and are ideal tools for investigating the concepts of variation, selection, and evolution.

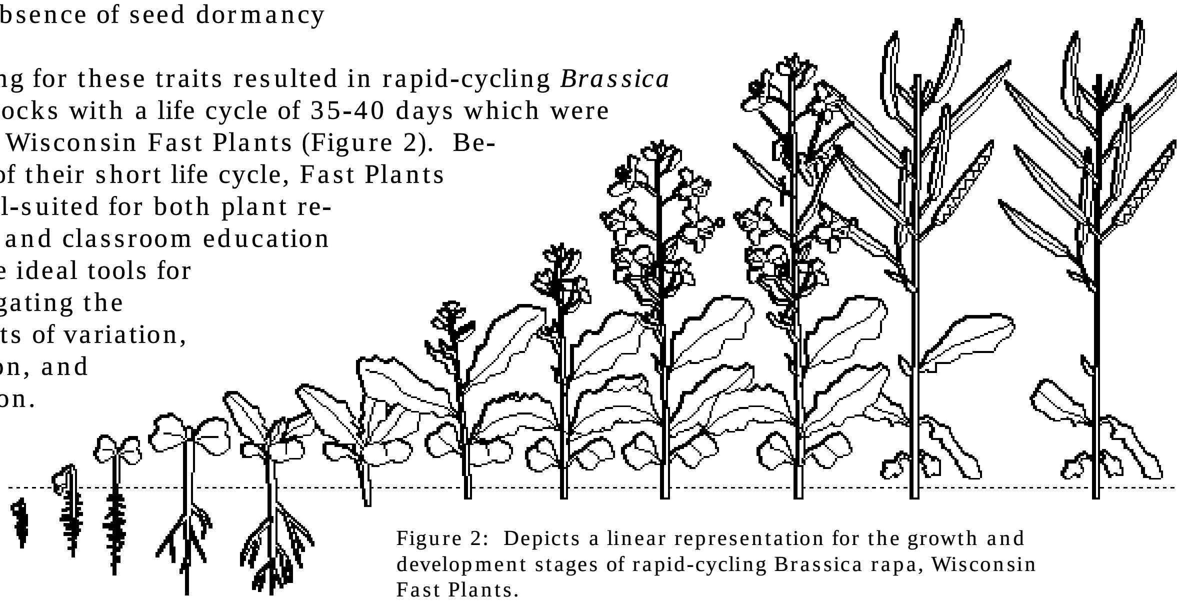

Figure 2: Depicts a linear representation for the growth and development stages of rapid-cycling Brassica rapa, Wisconsin Fast Plants.

Background

If you have grown Fast Plants, or any other plant, you may have noticed *variation* in particular characteristics among the individual plants within the population. In other words, every plant was different in some ways. This variation in physical traits, or **phenotypes** (such as plant color, height, or number of leaves), is considered to be the expression of the genetic makeup (**genotype**) of the individual as it interacts with the **environment** at a particular **stage of development** (Figure 3). Two genetically identical plants grown in two different environments, one with light and the other without light, may look similar as the seedlings emerge. However, seven days later, the plant with no light will be weak and struggling to survive, whereas the plant with the light will be more robust and developing normally.

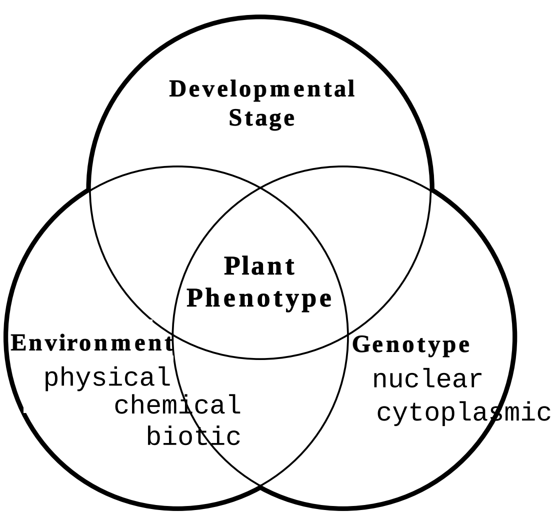

Figure 3: Diagram depicting the interrelationships of genotype, environment, and the development on the plant phenotype.

In nature, some individual plants possess characteristics that are more advantageous for survival than others in a particular environment. These individuals are considered to be more "fit" and are likely to produce offspring or *progeny* and eventually represent a larger portion of the inbreeding population in subsequent generations. This process, referred to as *natural selection*, is what Charles Darwin regarded as a major process driving *evolution*.

Plant breeding, however, relies on human guided or *artificial selection*. Breeders sift through the variation in a population and select individuals with desirable traits. They concentrate their efforts on one or a few phenotypes of interest such as plant utility, or adaptability to a particular agricultural setting, or color. Unlike natural selection, artificial selection tends toward a desired goal and is generally faster because only individual plants with the desired traits are allowed to reproduce. Through developing their own selection criteria, plant breeders can investigate the expression and inheritance of the trait. By exerting selection on a subpopulation of the species over repeated generations the breeder may alter the frequency of expression for a desired phenotype until it becomes stabilized or fixed in the subpopulation. For example, the repeated selection for succulent stems and flowers in wild *Brassica oleracea* ultimately produced broccoli as we see it today in our grocery stores.

Variation, Selection, and Evolution

By observing the variation among Fast Plants and focusing on different traits for selection purposes, students will be faced with the challenge of plant breeding. In a population of Fast Plants there are a number of variable traits that students might select. A brief list may include:

- Plant height
- Total number of leaves
- Width of the cotyledon
- Total number of flowers
- Days to the first flower

Though all of these traits are ideal for investigating the concepts of variation, selection as they relate to evolution, one trait in particular, namely hairiness, has captured the attention of scientists, teachers, and students as a model for investigating these concepts. Upon careful observation of Fast Plants, hairs can be seen on the stems and leaves. Further observation reveals that the number of hairs varies from plant to plant. Some plants have few or no hairs while others are very hairy.

The hairy phenotype provides an excellent opportunity for students to explore a highly variable phenotype. Investigating variation, selection, and the inheritance of hairs on Fast Plants can be an open-ended inquiry-based activity that will allow the students to develop and test hypotheses, design experiments, analyze data, and communicate results. Hairy's Inheritance is an opportunity for students to participate in real research since many questions relating to the inheritance of hairs remain unanswered.

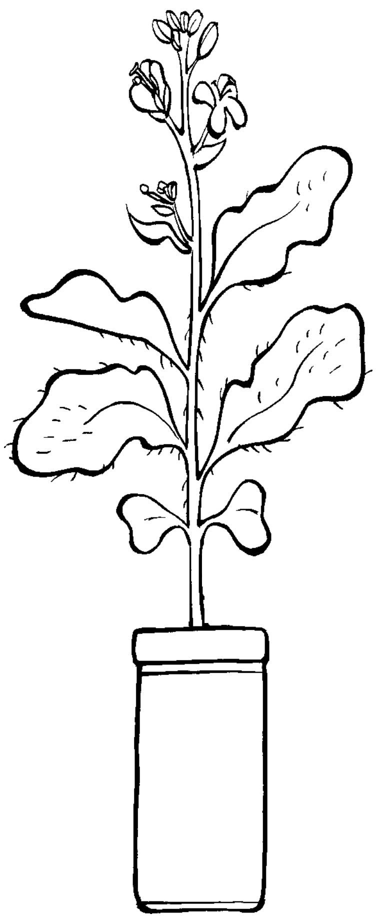

Figure 4: Depicts a hairy Fast Plant. The hairs on Fast Plants allow students to investigate variation, artifical selection and evolution.

For example, scientists are not sure why plants have hairs. They hypothesize that hairs play a role in defense against predators, aid in the absorption of water and nutrients, and aid in the reflection of sunlight. How hairs are inherited is just beginning to be understood; researchers are currently attempting to unravel how many genes regulate the number and location of hairs on Fast Plants. Research has documented that the number of hairs on a plant appears to be regulated by many genes and is considered to be quantitatively inherited (J. Agren et al., 1992), while the absence of hairs on some *Brassica rapa* varieties is controlled by a single gene (K.M. Song et al., 1995).

The hairs found on Fast Plants constitute a trait that is both quantifiable and heritable. Quantifying hairs is simple; they can be counted on the stem, petioles, leaf blades, and the edge of a leaf (Figure 4). The heritability of hairs is more complex and will provide students with the opportunity to develop their own investigations and create their own criteria for selection of hair numbers.

Where to begin: Observing and Counting

I. Before students develop criteria for selecting hairs, they first need to observe the distribution and number of hairs on their Fast Plants. They can examine the plants, notice where hairs appear, and describe or sketch their location.

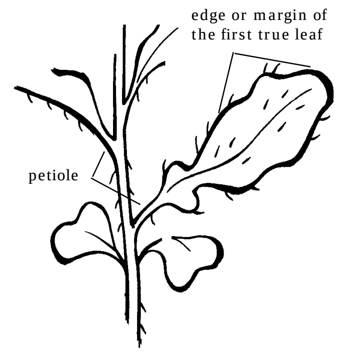

Figure 5: Suggested areas to count hairs on Fast Plants.

II. Next, students need to decide where on the plant they could accurately count the hairs. It is unnecessary to count all of the hairs on a plant. The number of hairs on one part of the plant appears to be strongly correlated with hairiness on other parts of the plant. [Hint: It may be easiest to count the hairs around the edge of the first true leaf or on the petiole. This can be done as early as Day 8 or 9 in the life cycle when the first true leaf is well developed (Figure 5)]. Students will need a good lighting source (preferably coming over their shoulder) and a hand lens. By observing the plant against a dark, contrasting background (construction paper, a classmate's sweater, etc.), it may be easier to count the hairs on the specified plant part.

Hairs on First True Leaf Margin of Rapid-cycling *Brassica rapa*, Basic Fast Plants

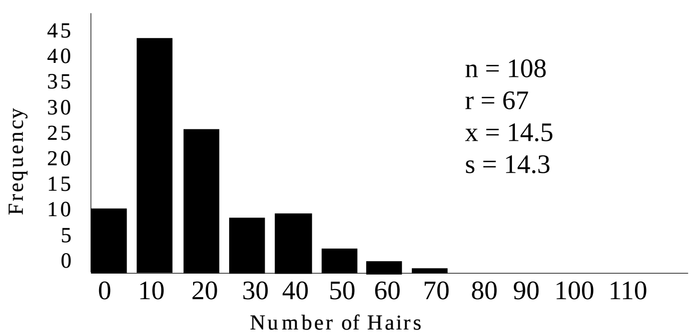

Figure 6: Frequency histogram shows the number of hairs in a population of rapid-cycling *Brassica rapa*

III. After each student has counted and recorded the number of hairs all the data from the class can be depicted as a statistical summary for the entire population, including population size (n), range in hair counts (r), the mean (average) number of hairs (x), and the standard deviation (s). Statistics and frequency histograms of hairs can help students visualize how hairs are distributed in a population of Fast Plants (Figure 6). From observing the graph, students will be able to identify patterns of the hairy phenotype within the population.

Analysis and Selection

IV. After looking at their graphed data and statistics, students can brainstorm ideas and develop questions relating variation, selection, and the inheritance of hairs. Questions may include: Is hairiness inherited? How is hairiness inherited? Could hairless or super-hairy populations be produced?

If the students choose to select the top ten percent of the hairiest plants in the class population as an experimental subpopulation and intermate (pollinate) only those plants, students would be applying artificial selection pressures on the population. This form of artificial selection is referred to as *directional selection* because it changes the mean value of a trait in a single direction (Figure 7). If hairiness is inherited through the combined effect of many different genes, one might expect that by repeatedly selecting the hairiest parents for subsequent generations the number of genes influencing hairiness in the population would increase. Will this directed selection increase the mean (average) for hairiness?

To investigate variation and selection, students should first record the number of hairs for the experimental group of parent plants. This will allow them to compare the initial data with the number of hairs counted on the next generation (the progeny or offspring). Will the offspring of the first intermating (F_1) have more hairs on average than the original population? Through how many generations would the students have to repeat the directional selection experiment before producing a super-hairy plant?

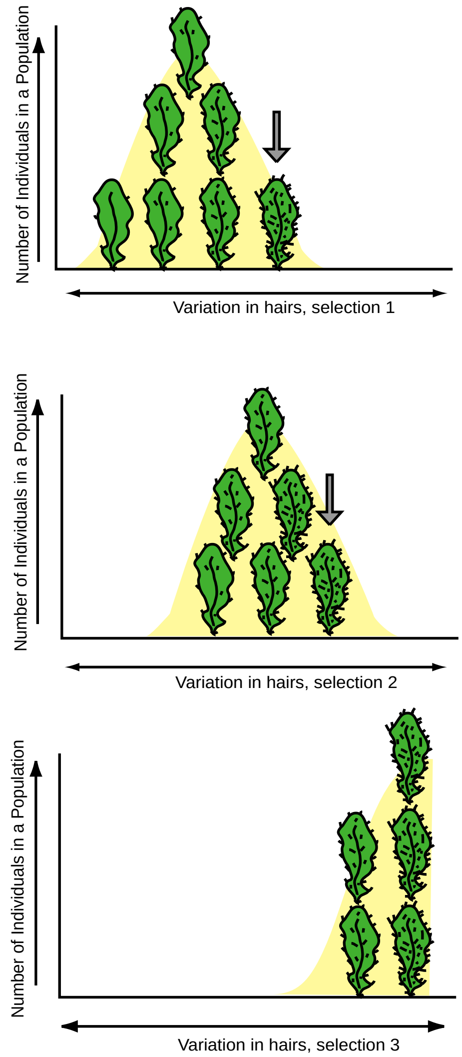

Figure 7: Depiction of directional selection, variation in the number of hairs on Fast Plant leaves, as an example. A bell-shaped curve (yellow) represents the range of variation in the number of hairs on a leaf.

Summary

Variation, selection, and evolution are difficult biological concepts to understand and challenging to model in a classroom setting. The short life cycle of Fast Plants provides the students with the potential to observe the variation and select for three generations within one semester. Through the process of counting, selecting, and intermating hairy Fast Plants, students will begin to see first hand how variation, selection, and evolution are interrelated.

Note to teachers: Barring crop failure, it is almost certain that by applying selection on the hairy phenotype, the mean number of hairs in the next generation will be different. Bruce Fall at the University of Minnesota has demonstrated the heritability of hairiness in an undergraduate biology lab by having his students select for the number of hairs on the petiole of the first true leaf. Starting with a population with a mean number of 8.8 hairs per individual, hairs were completely eliminated from the smooth-selected (less hairy) lineages after 10 generations of recurrent selection for hairlessness. Conversely, by selecting and intermating the 10% hairiest plants in each successive generation, the mean hair number has been increased to over 105 in 10 generations (B. Fall et al., 1995).

Further investigations

Extension 1: Hairy x Hairless

For those students and teachers who want to go beyond selection of the hairy trait and explore more defined patterns of inheritance for this trait, the Wisconsin Fast Plants Program has developed two Fast Plants stocks ideal for these investigations: **Hairless (0-1)** and **Hairy (5-8)**. Each of these stocks has been developed through the process of directional selection in order to investigate the nature of the inheritance patterns of hairs. If the hypothesis that the presence or absence of hairs is controlled by a single recessive gene is true then:

- Will the progeny of a hairy and a hairless cross have hairs?
- Will all the offspring of the F_1 generation have hairs?
- What ratio of hairy to hairless might you expect to observe in the F_2?

Extension 2: Developing a Scale for Hairiness (Hir)

In order to communicate observations, it is necessary to develop a notation to describe the hairy phenotype. Quantitative phenotypes which show a wide variation in their expression can be described using a scale from 0-9 rather than counting the number of hairs. The hairy phenotype is described as Hir 3-6. This particular symbol, Hir, is derived from the term *hirsute* (after the Latin for “hair”). On a scale from (0-9):

- (0) = no expression (no hair)
- (1-2) = low expression (few hairs)
- (3-6) = intermediate expression (hairs)
- (7-8) = high expression (many hairs)
- (9) = very high expression (very hairy)

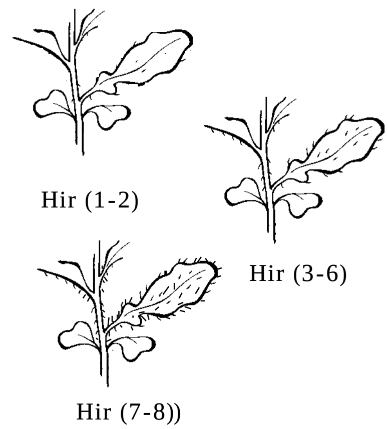

Figure 8: A diagram illustrating the (0-9) point scale developed to quantify the number of hairs on a Fast Plant.

(Figure 8) By counting the number of hairs in a defined area on the plant, you can convert the (0-9) scale to a graph depicting the relationship of the scaling numbers 0-9 (the independent variable or the X axis) and the actual count of hairs (the dependent variable or Y axis). What is the relationship of your scale to the number of hairs counts? Is it linear or logarithmic?

Extension 3: The Environment and Phenotype

Environment is a key element in the expression of a phenotype. The degree to which components of the environment, such as light, temperature, and nutrition contribute to the expression of phenotypes is an important part of genetics.

Little is known about the influence of environmental factors on the inheritance of hairiness. Investigation by students might provide insight into the influence of these and other environmental factors on the expression of the hairy phenotype.

Environmental applications:
Students may ask why plants have hairs at all. Does there have to be a purpose for any given trait on a plant? What are their hypotheses? A few scientists have asked the similar questions. How might students test their hypotheses?

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