NATURAL HISTORY MUSEUM
LOS ANGELES COUNTY

# Plant Parenthood

## $9^{th}$ - $12^{th}$ Grade

### Duration
Pre-Visit:
1-2 class sessions

Visit: 60 minutes

Post-Visit: 1 class

### Location
Edible Garden

### Supplies

- Projector (optional)
- Clipboard
- Pencil or Pen
- Worksheets
- Plant Trait Menu

### Standards

HS-LS3
Heredity: Inheritance and Variation of Traits

Science and Engineering Practices (many)

### Vocabulary

- **Artificial selection**: the intentional reproduction of individuals in a population that have desirable traits. Also known as "selective breeding"
- **Allele**: one of the possible forms of a gene. Most genes have two **alleles**, a dominant **allele** and a recessive **allele**

## Concepts

- Artificial selection is the process through which humans select and breed organisms to exhibit specific traits.
- The traits of offspring produced by crossing varieties of edible plants can be predicted by utilizing patterns of genetic inheritance.

## Objectives

- Students will understand what artificial selection is and compare it to natural selection.
- Students will predict the genetic and phenotypic outcomes of Mendelian test crosses.

## Outline

1. In one classroom session before visiting the Museum, explore artificial selection using plant breeding as an example. Prepare for the Museum activity by choosing target plants and researching their traits.
2. At the Museum, observe at least two varieties of the test plant and choose traits to breed for (or out). Perform F1 and F2 generation test crosses between chosen parent plants to see if traits can be selected for.
3. Back in the classroom, give students time to complete the assignment and discuss the results.

## References & Resources

**For Teachers**

- **Garden Genetics, Teaching with Edible Plants** by Elizabeth Rice, Marianne Krasny and Margaret E. Smith. Available through the NSTA Learning Science Store at *www.nsta.org/store*
- **Sunset Western Garden Book** by the Editors of Sunset Magazine
- **Botany for Gardeners** by Brian Capon
- **Learn Genetics** by University of Utah Health Sciences, *learn.genetics.utah.edu*

- **Colewart and the Cole Crops** by University of California Los Angeles at *www.botgard.ucla.edu/html/botanytextbooks/economicbotany/Brassica/index.html*
- **Identifying 50 Common Plant Families in Temperate Regions,** *www.rci.rutgers.edu/~struwe/pdfs/50plfamCOLOR.pdf*

**For Students**

- **Gregor Mendel and the Principle's of Inheritance** by Ilona Miko www.nature.com/scitable/topicpage/gregor-mendel-and-the-principles-of-inheritance-593#
- **The California Garden Web** by University of California at ucanr.edu/sites/gardenweb/Vegetables/
- **A Tree of Genetic Traits** by University of Utah at learn.genetics.utah.edu
- **Glossary of Plant Terminology** by University of Florida's Institute of Food and Agriculture plants.ifas.ufl.edu/education/glossary.html
- **Reviving America's Food Traditions** by Gary Paul Nabhan
- **Pantry Garden Herbs by Sullivan's Greenhouse,** a commercial site with an index of herb varieties and their descriptions. At pantrygardenherbs.com/shop-for-organic-herbs/

## Creating A Trait Menu

This lesson comes with prepared trait menus, but you can create your own with a little research about a plant (or plants) you would like students to explore.

1. Pick a plant type, then what traits you want to focus on (e.g. aspects of the fruit, flower, leaf, growth pattern and etc,). We suggest picking traits that have some interesting variation.

2. List observable phenotypes the plant exhibits and determine if any of them are fixed for the plant's whole group. Fixed traits can be eliminated from the list of potential traits to select for. *Identifying 50 Common Plant Families in Temperate Regions* is a good resource for this.

3. Figure out inheritance patterns and designate alleles to complete the menu. If the answer is not readily available, you may need to use inductive reasoning based on other peoples outcomes to determine these.

4. Place this information in a menu for use in the cross breeding.

Remember, this is not meant to be a definitive resource! Genetic interactions are complex, and new discoveries about gene behavior and inheritance are always being made. The purpose of this lesson is to consider how genes might interact and get a sense of what it means to artificially select for traits.

## Pre-Visit

Lead a discussion about edible plants, introducing the idea that edible plants have desired traits because of human interaction. Discussion questions might include:

- What types of plants do you eat or use?
- Do you cook with them?
- What qualities about them do you like or dislike?
- How might these plants influence culture?
- Are there special occasions you prepare certain foods?
- What is their availability (seasonal/regional/access in markets)?
- What is your favorite?
- If you could change one thing about one of these plants, what would it be, and why?

Explain that many plants, including crop plants (or plants we eat), are bred to enhance traits that we want (such as size, flavor, amount of edible portions, increased shelf-life) and/or decrease traits we don't want (such as flavor, inedible portions, or noxious chemicals/repellent properties). Go through the PDF slides (below) with students to explore and discuss how plants have been impacted by human selection for traits, introducing the concept of **artificial selection**.

Next distribute *You are a plant breeder* worksheet to begin, or have students start a record their project work in a notebook or journal using the worksheet as an outline. Tell students that what is planted in the Edible Garden can vary from season to season and year to year, however the following specimens have varieties available nearly year round at the Natural History Museum: mint, oregano, rosemary, sage and thyme. For this reason they should choose two potential plants to investigate during their visit to the Edible Garden at the Natural History Museum— one primary choice and one back-up.

In class or as homework, consider asking students to research the plant types they are going to focus on, creating a list of the varieties they might see and getting an idea of what traits they tend to exhibit.

*Teacher's Note: This lesson is not meant to be an introduction to Mendelian Genetics, and works best if this is a skill applies from a prior lesson. Additionally, you may choose to pre-visit the Museum right before your visit to see what is available for this activity and create your own plant-trait menu.*

## Museum Visit

At the Museum, have students find different varieties of their plant in the Edible Garden and record observations about the varieties, including morphology, scent, growth pattern and other observable traits. Students may touch and smell plants, just not pick and eat (consider bringing specimens for students to taste in the classroom).

If there is time, hand out relevant *Trait Menus* to students so they can continue working through the worksheet at the Museum with access to plants so they can make further observations if necessary. If there is no time, students can continue to work at home and/or back in the classroom.

*Teachers Notes:*

*You may opt to create your own plant trait menu using plants you know to be seasonally available in the NHM Edible Gardens, see the outline of how to do this below.*

*Alleles on the slides are represented with different letters than on plant trait menus (to help clarify which trait the student is working with). They should be handled in a Punnett square in the same way, regardless of the letter.*

## Post-Visit

Back in the classroom, discuss the results of the breeding, using the questions on the worksheet to guide the initial points. Additional discussion questions might include:

- What kind of information are we making assumptions about? (e.g. different genotypes for the same phenotype, seasonal impacts on protein production, viability of offspring in other respects, etc.)
- How might we be able to tell if a parent had a genotype was heterozygous vs. homozygous in actual practice?
- What other kinds of traits might be considered 'valuable' that were not explored?
- How is natural selection different than artificial selection? How are they similar?
- What kind of research questions might come from this practice?

## Variations & Extensions

- Have students create the plant trait menus.
- Use this lesson, or aspect of this lesson, as a focus point for the Question Formulation Technique rightquestion.org/educators/resources
- Discuss what makes a question scientific, and what makes a good scientific question.

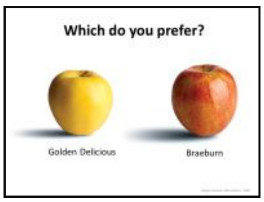

## Plant Parenthood

Briefly introduce the project to the class, explaining that they will be breeding plants using their knowledge of genetic inheritance to select for traits they would like to see in a crop. But first, what is *Artificial Selection*? Explain that many, if not most, of the plants we eat today have been bred with specific goals in mind. For example…

## The Apple


The apple. When we think of an apple, we think of a mostly round, brightly colored, usually sweet and crisp fruit that we can buy in different kinds. Every different kind of apple we see in the store is actually the same species Malus domestica. Within the apple species, there are thousands of kinds that look and taste and little differently because they are different varieties.  Varieties are slightly, genetically different versions of the same species of plant.

Ask students: What differences do you notice between these varieties? How might varieties come to be? It is a matter of preference.

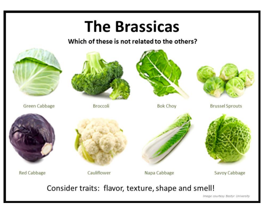



## Which do you prefer? (2 slides)

Ask students: Which do you prefer? Why?
*Teachers Note: Consider collecting samples of apple varieties for students to try*

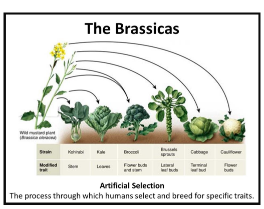

## What traits might farmers prefer? Consumers?

In addition to these (student) ideas, other important considerations for breeding edible and crop plants include shelf life, nutrition, durability during packing and shipping, and aesthetics. All of these many desired traits are selected for by breeders, and this selection is how different varieties come to be. Lets take a look at another example:




## The Brassicas (1)

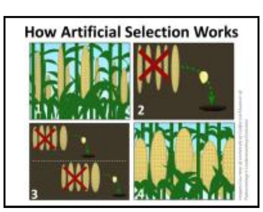
Like apples, all of these vegetables are different varieties of the same species! Each variety is bred repeatedly to enhance desirable traits.




## The Brassicas (2)

We call this process Artificial Selection, the process through which humans select and breed for specific traits. For example, all of these vegetables have been bred over the course of generations to emphasize different traits from the same species of wild mustard:

- Kohlrabi is an enlarged stem
- Kale is enlarged leaves and different textures– curly, wavy, bumpy
- Broccoli is the increased number of flower buds; enlarged stem
- Brussel sprouts are emphasized Leaf buds
- Cabbage is the reduced length between leaves




## How Artificial Selection Works (1)

1. Natural variation among a species occurs in the wild population.
2. People choose a trait that they like from a wild plant, and plant seeds only from plants expressing (showing) that ideal trait.
3. This process of people choosing traits and planting repeats over and over again, across many generations.
4. Over time a variety of the original species that emphasizes the desired trait is developed.

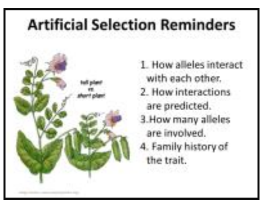
Unless cloned, flowering plants don't act solo to reproduce, they mix different individuals' genetic material, i.e. they reproduce sexually. Sexual reproduction in plants is achieved through pollination (i.e., fertilization by pollen).

*Teachers note: Not all plants reproduce sexually (through pollination)! Many asexually reproduce, and genetic variation comes form mutation. This particular lesson plan focuses on sexually reproducing plants. Additionally, many plants bred for crops that are in an 'ideal' state (such as apples) are cloned by grafting or planting cuttings from a parent. This ensure no genetic changes, and thus consistency in the crop.*


## How Artificial Selection Works (2)

Pollination combines plant genes, just like sex combines our genes. Each parent contributes chromosomes to offspring, chromosomes that contain genes responsible for the expression of traits in their offspring. For flowering plants, 'male' pollen grains are carried to the 'female' parts of the flower to create a seed through a natural pollinator, such as water, wind, insects (shown left), birds or other animals.

In artificial selection, the role of the pollinator may be played by people, who choose specific individuals of the same species that they want to cross-breed. In the picture 'male' pollen from one plant is delivered to another plant's 'female' parts (shown right). Controlling pollination allows us to specifically cross breed individuals to emphasize the traits we want! But how do we know which individuals to cross with who? For this, we need to remember how genes are inherited and expressed.




## Artificial Selection Reminders

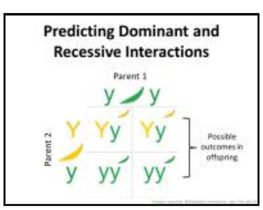
Before we can just start breeding plants willy nilly, unlike Natural Selection, Artificial Selection has a goal. We want to breed for a specific outcome. This means we need to recall some important information about genetics:

1. How alleles interact with each other
2. How interactions are predicted
3. How many alleles are involved
4. Family history

Remember Mendel and his peas? Mendel used artificial pollination to breed pea plants and observed and mathematically explained how traits were passed down to offspring from parents. Understanding how alleles interact is important when we are selecting what traits to breed for, because we need to know what the outcome of our breeding is likely to be. We look at gene interactions, and consider the possible outcomes in offspring using a Punnett square.


## Allele Interaction: Dominant and Recessive

One pattern of expression we see in traits (such as freckles, dimples, and in the example above, pea pod color) is that one allele is expressed over another. This is means it masks the effect of another allele, or it prevents an allele's basic proteins from forming. This kind of gene interaction is called complete dominance. One allele is dominant, expressing over a recessive allele. In this example, the dominant alleles blocks the formation proteins that become the green pigment.




## Predicting Dominant and Recessive Interactions

A Complete dominance Punnet square shows an allele pair from each parent represented on either side of table (remember, one allele comes from each parent, so the resulting offspring has a total of two). In this example of bean color, the presence of yellow pigment is the dominant trait (Y) and a green pigment is recessive (y). Parent 1 is homozygous for the recessive trait (green) and Parent 2 is heterozygous, expressing the dominant trait and carrying the recessive trait.

When you create Punnett square that combines these in the possible combinations offspring might have, you can see that the offspring of Parent 1 and Parent 2 have two possible genotypes and two possible phenotypes – there may be multiple outcomes of the offspring, including one that does not express the dominant trait.


## Allele Interaction: Incomplete and Codominance

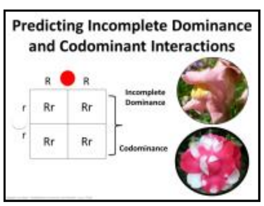
Other patterns of expression we see in traits are that one allele is not exclusively expressed, or dominant,  over another in heterozygous genotypes This is called Incomplete dominance or Codominance depending on how the traits are expressed in the phenotype.

When one allele does not completely mask the other, giving the offspring a blended or intermediate phenotype, it's called Incomplete dominance. For example, imagine a flower where one parent has alleles for a red phenotype, and the other codes for a white phenotype. In incomplete dominance, the result is a blended expression, a pink phenotype.

*Teachers Note: Some examples of incomplete dominance are the result of one allele coding for a protein and the other coding for nothing, i.e. it is a null allele - serving as a placeholder rather than an actively expressed allele. In this case, the blended expression is a result of less protein being coded for than would be necessary for a full on dominant effect.*

When both alleles share expression and do not mix, giving the offspring a mottled or spotty phenotype, it's called Codominance. Imagine the same parents as our previous example: one parent has alleles for a red phenotype, and the other codes for a white phenotype. In codominance, the result is that some parts of the flower are red, and the others white.

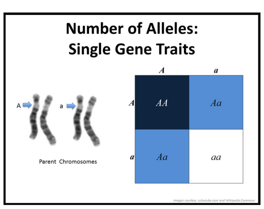
Ask students, which kind of interaction are we seeing in the flower to the left? (Incomplete). What about in the flower to the right? (Codominance).




## Predicting Incomplete Dominant and Codominant Interactions

These traits interactions can still be predicted using a Punnet square. For example, lets pretend we looking at a Punnett square for an allele that codes for color in flowers.

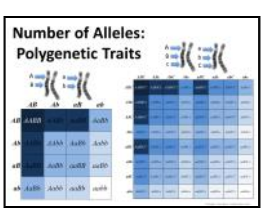
Parent one carries the alleles for red petals (RR) and the other parent carries the alleles for a white petals (rr). If this trait expresses Incomplete dominance, the color of the offspring will be a blend of both the red and white petal parents, so pink (shown top). If this trait expresses Codominance, the color of the offspring will be both red and white (shown bottom).




## Number of Alleles: Single Gene Traits

In the examples we just looked at, the Punnet squares were simple because they were exploring the outcomes of a single gene trait, traits that arise from only one allele, located in a single place on a chromosome. The possible outcomes of these combinations only result in two or three phenotypes. Because Mendel discovered these kind of interactions, you also often hear to single-gene traits as Mendelain traits.

But many traits may come from the interaction of genes that are located at several different places on the chromosome, these are called polygenetic traits.

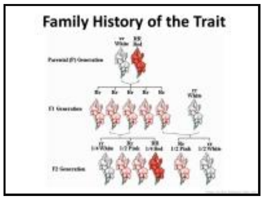



## Number of Alleles: Polygenetic Traits

Polygenetic traits can also be predicted using a Punnet square, but the table gets larger in order to represent all the possible interactions between alleles. (Note, alleles may not all come from the same chromosome. For the sake of clarity, only a single chromosome pair is shown on the slide)

Due to all the possible allele combinations that can be contributed by the parents, there is a range of possible pairings, and thus range of possible phenotypes in the offspring. If you look at the Punnet square to the left, where a trait has 2 gene locations (and thus, four possible parent contributions – don't forget chromosomes can cross during meiosis!), there are 5 possible phenotypes. If we had a trait with 3 genes locations, would could have up to 13 different phenotypes!

Polygenetic traits are often referred to as quantitative traits because their outcomes are a phenotype along a continuous range, like the distribution of a bell curve.




## Family History of the Trait

We know we want to select traits to emphasize (or de-emphasize). We know that to do this, it is important to consider how alleles interact with each other, how to predict the outcomes of those interactions and how many alleles might be involved in predicting those outcomes.

The last thing we need to keep in mind  is the family history of the trait, because all alleles come from somewhere! Knowing the genetic lineage will help make better predictions about what the offspring might look like two crosses down the line, because it will show how alleles interact (in the example above, via incomplete dominance) and what genotypes you want to breed together for the desired outcome (if you want only pink or red flowers, only breed pink with white).

However, even with a knowledge of the family history, there is still a lot left to chance. First, we have no idea which of the possible combinations will actually occur. Additionally, we might not be able to tell the genotype from the phenotype. As we saw earlier, there are a few different combinations of genes that can have the same phenotypic outcome. Even in artificial selection, there is uncertainty!


## The Plant Parenthood Project: Breed a New Variety of Plant

Explain the project to students, clarifying student questions and passing out materials as necessary.


Plant
Parenthood
Artificial Selection and you!
Image courtesy Twice25, Wikimedia Commons

# The Apple

## *Malus domestica*


Varieties: Different versions of the same species.

How do varieties come to be?

# Which do you prefer?

Golden Delicious

Braeburn

*Image courtesy WW Norton, Flickr*

# Which do you prefer?

Fuji

Granny Smith

*Image courtesy WW Norton, Flickr*

# What traits might farmers prefer? Consumers?

# The Brassicas

**Which of these is not related to the others?**

Green Cabbage

Broccoli

Bok Choy

Brussel Sprouts

Red Cabbage

Cauliflower

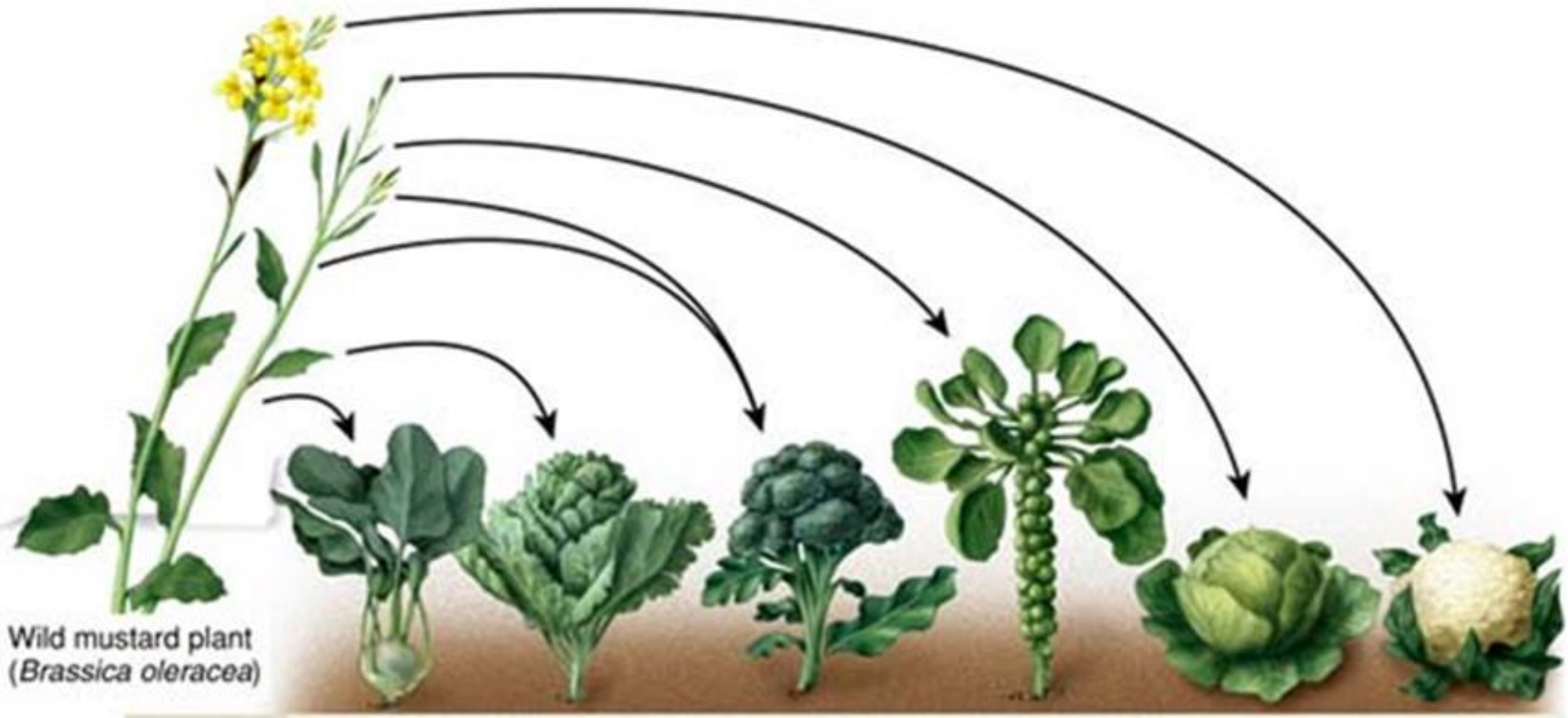
Napa Cabbage

Savoy Cabbage

Consider traits: flavor, texture, shape and smell!

*Image courtesy Bastyr University*

# The Brassicas

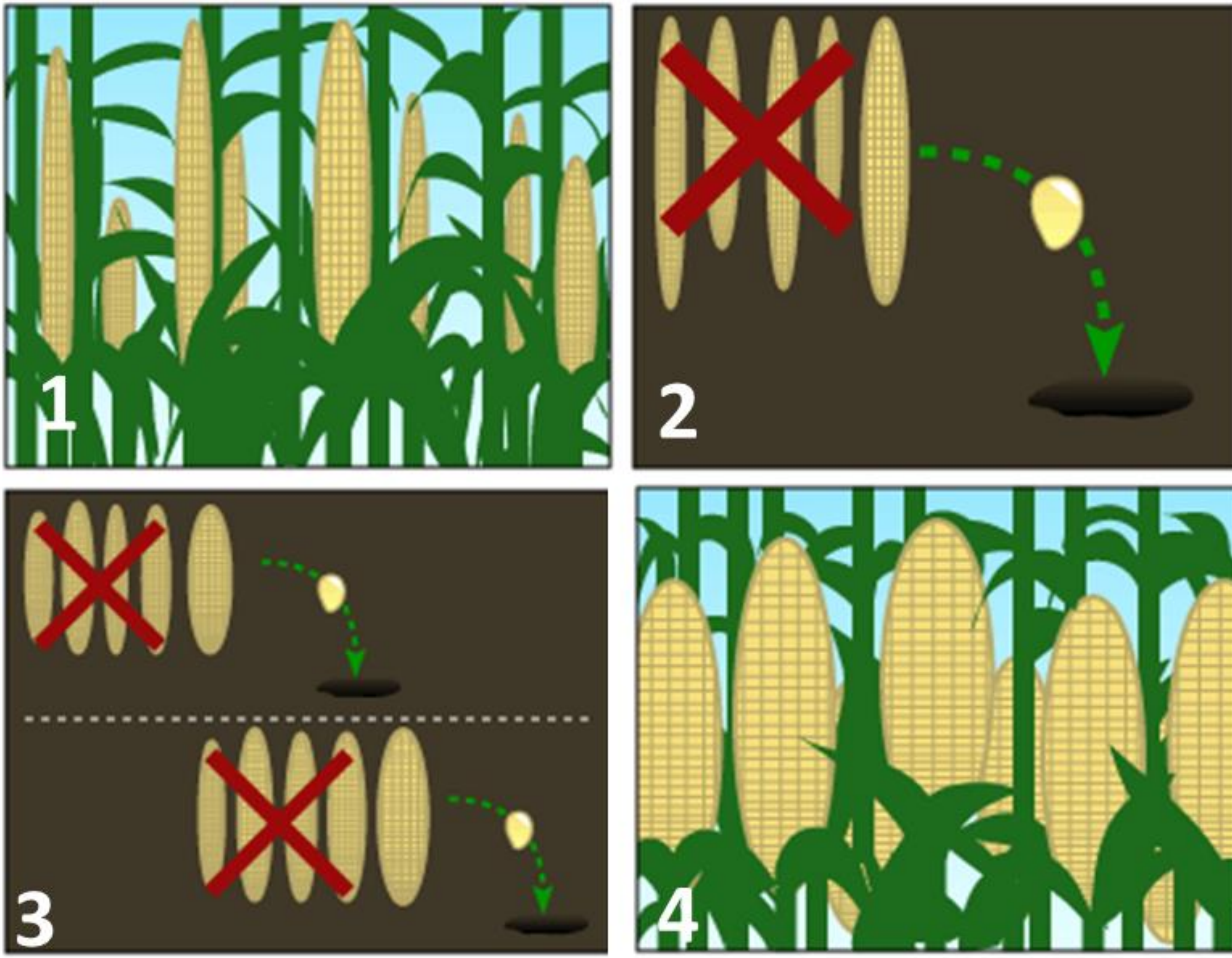



| Strain | Kohlrabi | Kale | Broccoli | Brussels sprouts | Cabbage | Cauliflower |
|---|---|---|---|---|---|---|
| Modified trait | Stem | Leaves | Flower buds and stem | Lateral leaf buds | Terminal leaf bud | Flower buds |

**Artificial Selection**

The process through which humans select and breed for specific traits.

# How Artificial Selection Works




*Images Courtesy of University of California Museum of Paleontology's Understanding Evolution*

# How Artificial Selection Works

Natural pollination via insect

Artificial pollination via human

# Artificial Selection Reminders

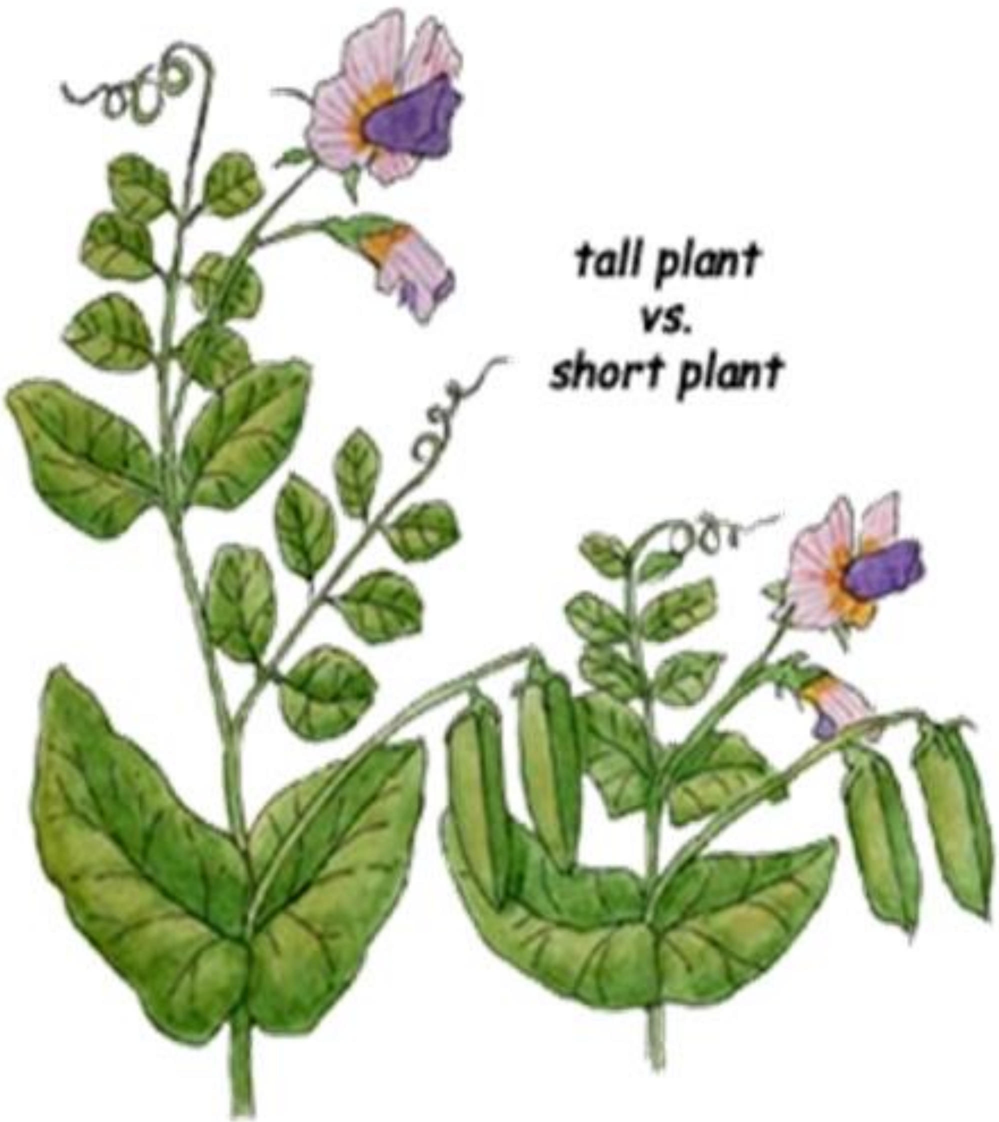
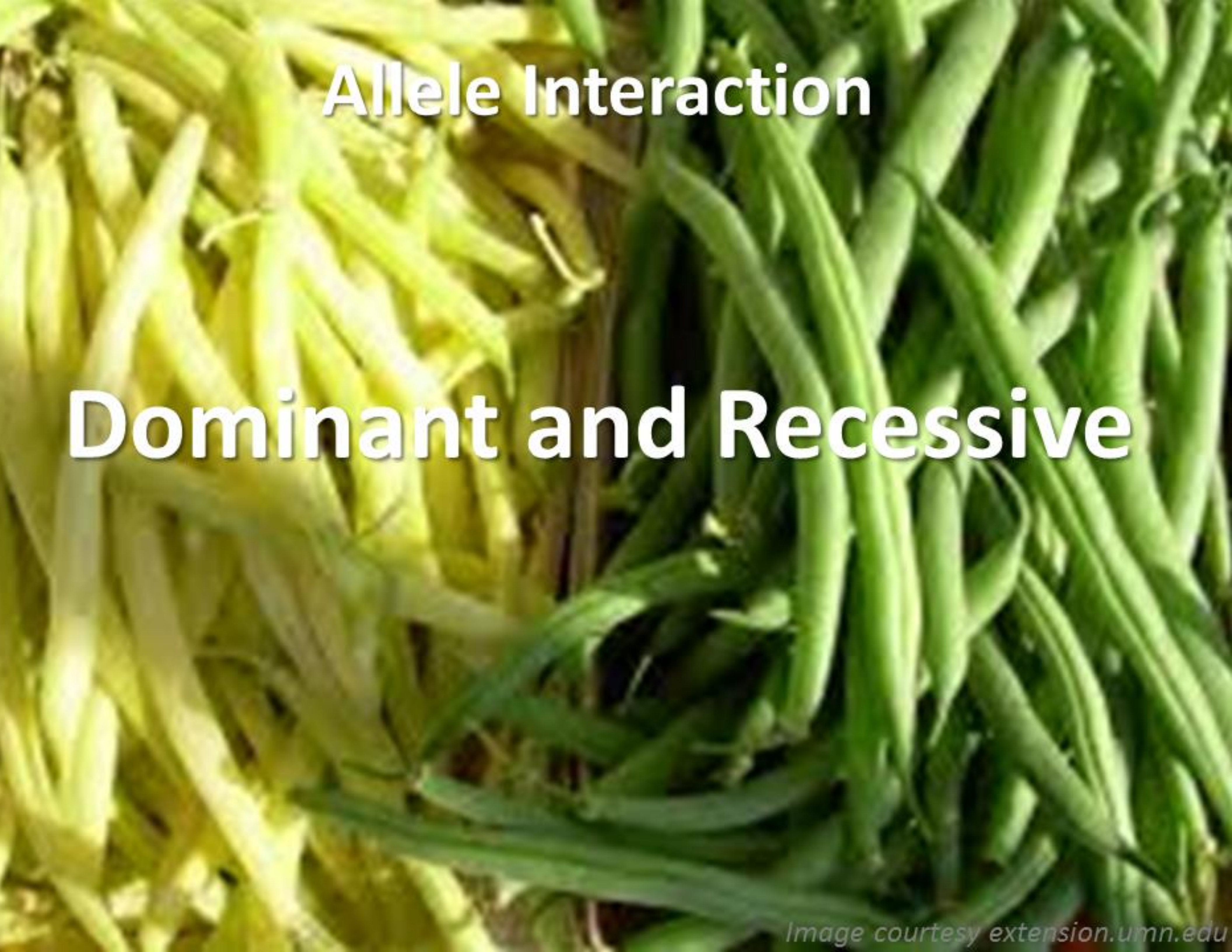



*Image courtesy www.exploringnature.org/*

1. How alleles interact with each other.
2. How interactions are predicted.
3. How many alleles are involved.
4. Family history of the trait.


Allele Interaction
Dominant and Recessive
Image courtesy extension.umn.edu

# Predicting Dominant and Recessive Interactions

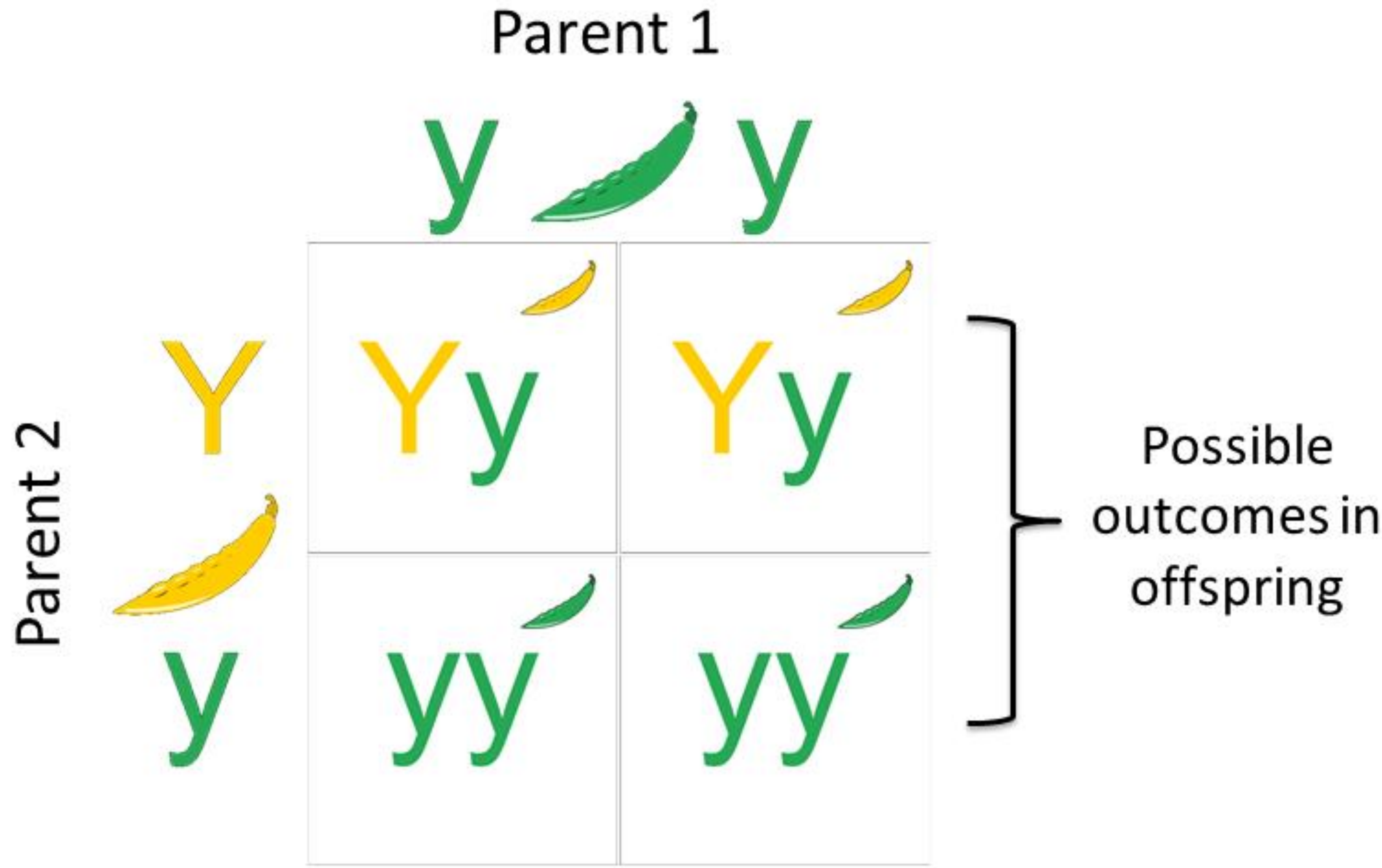



Image courtesy Wikipeida Commons, user Pbroks13

# Allele Interaction

# Incomplete & Codominance

Images courtesy Wikipedia Commons and darwin cruz, Flickr

# Predicting Incomplete Dominance and Codominant Interactions

| | R | R |
|---|---|---|
| r | Rr | Rr |
| r | Rr | Rr |

Incomplete Dominance

Codominance

Images courtesy Wikipedia Commons and darwin cruz, Flickr

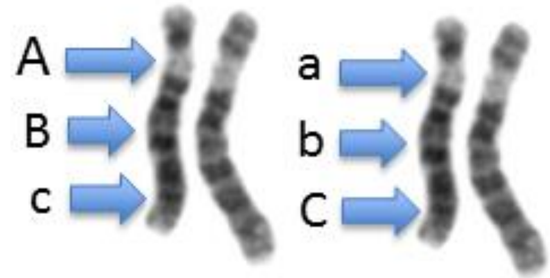
# Number of Alleles: Single Gene Traits

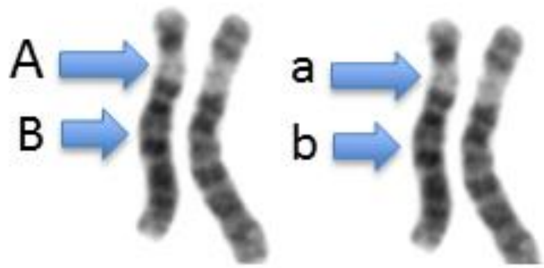

Parent Chromosomes

| | *A* | *a* |
|---|---|---|
| *A* | *AA* | *Aa* |
| *a* | *Aa* | *aa* |

Images courtesy cubocube.com and Wikipedia Commons

# Number of Alleles: Polygenetic Traits




| | *AB* | *Ab* | *aB* | *ab* |
|---|---|---|---|---|
| ***AB*** | *AABB* | *AABb* | *AaBB* | *AaBb* |
| ***Ab*** | *AABb* | *AAbb* | *AaBb* | *Aabb* |
| ***aB*** | *AaBB* | *AaBb* | *aaBB* | *aaBb* |
| ***ab*** | *AaBb* | *Aabb* | *aaBb* | *aabb* |

| | *ABC* | *ABc* | *AbC* | *Abc* | *aBC* | *aBc* | *abC* | *abc* |
|---|---|---|---|---|---|---|---|---|
| ***ABC*** | *AABBCC* | *AABBCc* | *AABbCC* | *AABbCc* | *AaBBCC* | *AaBBCc* | *AaBbCC* | *AaBbCc* |
| ***ABc*** | *AABBCc* | *AABBcc* | *AABbCc* | *AABbcc* | *AaBBCc* | *AaBBcc* | *AaBbCc* | *AaBbcc* |
| ***AbC*** | *AABbCC* | *AABbCc* | *AAbbCC* | *AAbbCc* | *AaBbCC* | *AaBbCc* | *AabbCC* | *AabbCc* |
| ***Abc*** | *AABbCc* | *AABbcc* | *AAbbCc* | *AAbbcc* | *AaBbCc* | *AaBbcc* | *AabbCc* | *Aabbcc* |
| ***aBC*** | *AaBBCC* | *AaBBCc* | *AaBbCC* | *AaBbCc* | *aaBBCC* | *aaBBCc* | *aaBbCC* | *aaBbCc* |
| ***aBc*** | *AaBBCc* | *AaBBcc* | *AaBbCc* | *AaBbcc* | *aaBBCc* | *aaBBcc* | *aaBbCc* | *aabbCc* |
| ***abC*** | *AaBbCC* | *AaBbCc* | *AabbCC* | *AabbCc* | *aaBbCC* | *aaBbCc* | *aabbCC* | *aabbCc* |
| ***abc*** | *AaBbCc* | *AaBbcc* | *AabbCc* | *Aabbcc* | *aaBbCc* | *aaBbcc* | *aabbCc* | *aabbcc* |

*Images courtesy cubocube.com*

# Family History of the Trait

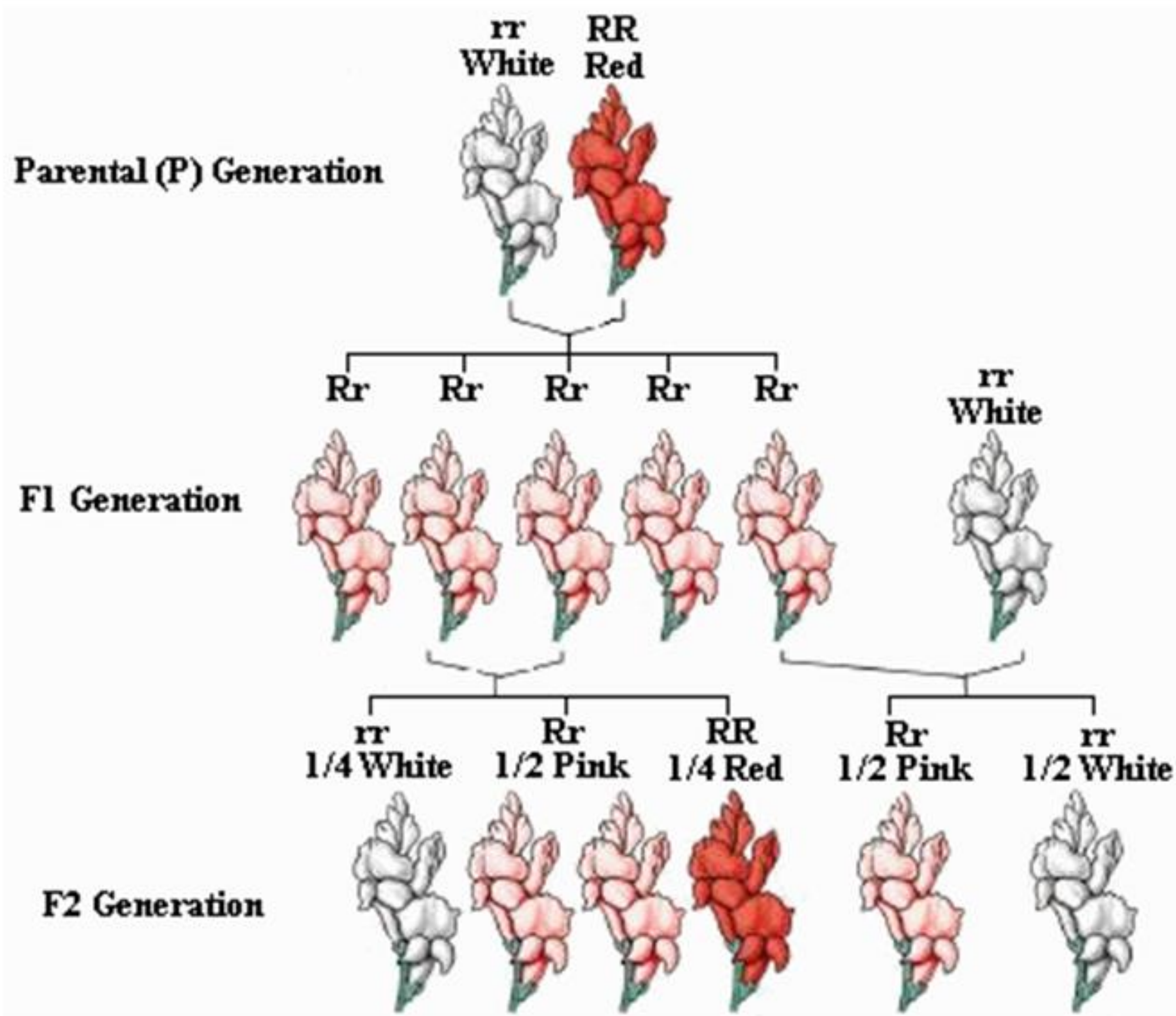



Image courtesy biologyjunction.com

# The Plant Parenthood Project: Breed a New Variety of Plant

## Observe

- Observe one of the suggested crops in the Nature Gardens, comparing at least two varieties .
- Record observations (sketch and text) to describing the traits of the varieties.
- Note a few traits you might like to select for

## Assign Alleles

- Choose the two traits you will select for.
- Use the Plant Trait Menu to help guide your choice, and note the pattern of inheritance

## Breed for the Trait

- Cross a pair of parent plants, and select offspring to emphasize desired traits and perform crosses for at least 2 generations of possible offspring.
- Reflect on your work, answering the questions on the worksheet.

# Trait Menu: Mint

***Genus Mentha***

| Trait Profile | Alleles | Phenotype/Genotype |
|---|---|---|
| **Leaf Color (L)**<br>*Polygenic, Incomplete or Codominance*<br><br>Each gene independently controls production of a leaf pigment, so resulting leaf color may be a blend of pigments.<br><br>Note: There are many genes and resulting pigments not listed in this table and can be tetraploidy (4 chromosomes). | Blue Green ($L^A$)<br>Yellow-Green ($L^B$)<br>Recessive (l) | Dark Blue-Green ($L^AL^All$)<br>Light Blue-Green ($L^Alll$)<br>Sap Green ($L^AL^AL^BL^B$)<br>Yellow-Green ($llL^BL^B$) |
| **Leaf Shape (S)**<br>*Polygenic, Codominance*<br><br>These genes determine shape of the leaf and exhibit a spectrum of phenotypes. | Oblong ($S^o$)<br>Elliptic ($S^E$)<br>Ovate ($S^v$)<br>Null (s) | Oblong ($S^oS^o$)<br>Slightly Oblong ($S^os$)<br>Elliptic ($S^ES^E$)<br>Slightly Elliptic ($S^Es$)<br>Ovate ($S^vS^v$)<br>Slightly Ovate ($S^vs$) |
| **Leaf Edge or Margin (E)**<br>*Single Gene, Complete Dominance*<br><br>Presence of this gene initiates programmed cell death to produce a serrated edge. | Serrated (E)<br>Null (e) | Serrated (EE or Ee)<br>Smooth (ee) |
| **Leaf Texture (H)**<br>*Single Gene, Incomplete Dominance*<br><br>Presences of the gene results in production of small hairs on the leaf. | Hairy (H)<br>Null (h) | Dense hairs (HH)<br>Some hairs (Hh)<br>No Hairs or smooth (hh) |
| **Leaf Flavor (F)**<br>*Polygenic, Incomplete or Codominance*<br><br>Taste of mint is based on the production of compounds by independent genes. The fewer compounds, the less flavor.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. Also, genes combine for a spectrum of flavors, and are tetraploidy (4 chromosomes). A strong mint chocolate flavor might be ($F^pF^pF^bF^b$) while a strong mint, hint of chocolate flavor might be ($F^pF^pF^{bf}$). | Peppermint ($F^P$)<br>Chocolate/Bitter ($F^B$)<br>Spicy/Cinnamon ($F^C$)<br>Lemon/Sour ($F^L$)<br>Null (f) | Strong mint ($F^PF^P$)<br>Light mint ($F^Pf$)<br>Very Bitter ($F^BF^B$)<br>Light bitter ($F^Bf$)<br>Strong spice ($F^CF^C$)<br>Light spice ($F^Cf$)<br>Strong sour ($F^LF^L$)<br>Light sour ($F^Lf$)<br>Flavor not present (ff) |
| **Scent or Aroma (A)**<br>*Polygenic, Incomplete or Codominance*<br><br>Aroma is determined by independent genes that produce oils in the leaf.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Mint ($A^P$)<br>Lemon ($A^L$)<br>Null (a) | Strong mint aroma ($A^PA^P$)<br>Light mint aroma($A^Pa$)<br>Strong Lemon aroma($A^LA^L$)<br>Light lemon aroma($A^La$)<br>No smell (aa) |
| **Flower Color (C)**<br>*Single Gene, Codominance*<br><br>Genes determine production of color pigments, alleles code for different variations of the pigment. | Blue-Purple ($C^B$)<br>Red ($C^R$)<br>Null (c) | Dark Blue Purple ($C^BC^B$)<br>Purple ($C^BC^R$)<br>Red ($C^RC^R$)<br>Light Blue Purple ($C^Bc$)<br>Light Pink ($C^Rc$)<br>White—no pigment (cc) |

# Trait Menu: Oregano

***Genus Origanum***

| Trait Profile | Alleles | Phenotype/Genotype |
|---|---|---|
| **Leaf Color (L)**<br>*Polygenic, Incomplete or Codominance*<br><br>Each gene independently controls production of a leaf pigment, so resulting leaf color may be a blend of pigments.<br><br>Note: There are many genes and resulting pigments not listed in this table and can be tetraploidy (4 chromosomes). | Blue Green ($L^A$)<br>Yellow-Green ($L^B$)<br>Recessive (l) | Dark Blue-Green ($L^AL^All$)<br>Light Blue-Green ($L^Alll$)<br>Sap Green ($L^AL^AL^BL^B$)<br>Yellow-Green ($llL^BL^B$) |
| **Leaf Edge or Margin (E)**<br>*Single Gene, Complete Dominance*<br><br>Presence of this gene initiates programmed cell death to produce a serrated edge. | Serrated (E)<br>Null (e) | Serrated (EE or Ee)<br>Smooth (ee) |
| **Leaf Width (W)**<br>*Single Gene, Complete Dominance*<br><br>Presence of gene determines width of leaf. | Wide (W)<br>Thin (w) | Wide leaf (WW or ww)<br>Thin leaf (ww) |
| **Leaf Texture (H)**<br>*Single Gene, Incomplete Dominance*<br><br>Presences of the gene results in production of small hairs on the leaf. | Hairy (H)<br>Null (h) | Dense hairs (HH)<br>Some hairs (Hh)<br>No hairs or smooth (hh) |
| **Leaf Flavor (F)**<br>*Polygenic, Incomplete or Codominance*<br><br>Taste of oregano is based on the production of compounds by independent genes. The fewer compounds, the less flavor.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. Also, genes combine for a spectrum of flavors, and are tetraploidy (4 chromosomes). A strong spicy oregano flavor might be ($F^OF^OF^CF^C$) while a lighter spicy flavor might be ($F^OF^OF^Cl$). | Oregano ($F^O$)<br>Spicy/Cinnamon ($F^C$)<br>Null (f) | Strong oregano ($F^OF^O$)<br>Light oregano ($F^Of$)<br>Strong spice ($F^CF^C$)<br>Light spice ($F^Cf$)<br>Flavor not present (ff) |
| **Scent or Aroma (A)**<br>*Polygenic, Incomplete or Codominance*<br><br>Aroma is determined by independent genes that produce oils in the leaf.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Oregano ($A^O$)<br>Lemon ($A^L$)<br>Null (a) | Strong oregano aroma ($A^OA^O$)<br>Light oregano aroma ($A^Oa$)<br>Strong Lemon aroma ($A^LA^L$)<br>Light lemon aroma ($A^La$)<br>No aroma (aa) |
| **Flower Color (C)**<br>*Single gene, Codominance*<br><br>Genes determine production of color pigments, alleles code for different variations of the pigment. | Blue-Purple ($C^B$)<br>Red color ($C^R$)<br>Null (c) | Dark Blue Purple ($C^BC^B$)<br>Purple ($C^BC^R$)<br>Red ($C^RC^R$)<br>Light Blue Purple ($C^Bc$)<br>Light Pink ($C^Rc$)<br>White—no pigment (cc) |

# Trait Menu: Rosemary

***Genus Rosemarinus***

| Trait Profile | Alleles | Phenotype/Genotype |
|---|---|---|
| **Leaf Color (L)**<br>*Polygenic, Incomplete or Codominance*<br><br>Each gene independently controls production of a leaf pigment, so resulting leaf color may be a blend of pigments.<br><br>Note: There are many genes and resulting pigments not listed in this table and can be tetraploidy (4 chromosomes). | Blue Green ($L^A$)<br>Yellow-Green ($L^B$)<br>Null (l) | Dark Blue-Green ($L^A L^A ll$)<br>Light Blue-Green ($L^A lll$)<br>Sap Green ($L^A L^A L^B L^B$)<br>Yellow-Green ($llL^B L^B$) |
| **Leaf Edge or Margin (E)**<br>*Single Gene, Complete Dominance*<br><br>Presence of this gene initiates programmed cell death to produce a serrated edge. | Serrated (E)<br>Null (e) | Serrated (EE or Ee)<br>Smooth (ee) |
| **Leaf Width (W)**<br>*Single Gene, Complete Dominance*<br><br>Presence of gene determines width of leaf. | Wide (W)<br>Thin (w) | Wide leaf (WW or ww)<br>Thin leaf (ww) |
| **Leaf Texture (H)**<br>*Single Gene, Incomplete Dominance*<br><br>Presences of the gene results in production of small hairs on the leaf. | Hairy (H)<br>Null (h) | Dense hairs (HH)<br>Some hairs (Hh)<br>No hairs or smooth (hh) |
| **Leaf Flavor (F)**<br>*Polygenic, Incomplete or Codominance*<br><br>Taste of rosemary is based on the production of compounds by independent genes. The fewer compounds, the less flavor.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. Also, genes combine for a spectrum of flavors, and are tetraploidy (4 chromosomes). A strong spicy rosemary flavor might be ($F^R F^R F^C F^C$) while a light spice flavor might be ($F^R F^R F^C f$). | Rosemary ($F^R$)<br>Spicy/Cinnamon ($F^C$)<br>Null (f) | Strong rosemary ($F^R F^R$)<br>Light rosemary ($F^R f$)<br>Strong spice ($F^C F^C$)<br>Light spice ($F^C f$)<br>Flavor not present (ff) |
| **Scent or Aroma (A)**<br>*Polygenic, Incomplete or Codominance*<br><br>Aroma is determined by independent genes that produce oils in the leaf.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Rosemary ($A^R$)<br>Lemon ($A^L$)<br>Null (a) | Strong rosemary aroma ($A^R A^R$)<br>Light rosemary aroma ($A^R a$)<br>Strong Lemon aroma ($A^L A^L$)<br>Light lemon aroma ($A^L a$)<br>No aroma (aa) |
| **Flower Color (C)**<br>*Single gene, Codominance*<br><br>Genes determine production of color pigments, alleles code for different variations of the pigment. | Blue-Purple ($C^B$)<br>Red color ($C^R$)<br>Null (c) | Dark Blue Purple ($C^B C^B$)<br>Purple ($C^B C^R$)<br>Red ($C^R C^R$)<br>Light Blue Purple ($C^B c$)<br>Light Pink ($C^R c$)<br>White—no pigment (cc) |

# Trait Menu: Culinary Sage

***Genus Salvia***

| Trait Profile | Alleles | Phenotype/Genotype |
|---|---|---|
| **Leaf Color (L)**<br>*Polygenic, Incomplete or Codominance*<br><br>Each gene independently controls production of a leaf pigment, so resulting leaf color may be a blend of pigments.<br><br>Note: There are many genes and resulting pigments not listed in this table and can be tetraploidy (4 chromosomes). | Blue Green ($L^A$)<br>Yellow-Green ($L^B$)<br>Null (l) | Dark Blue-Green ($L^AL^All$)<br>Light Blue-Green ($L^Alll$)<br>Sap Green ($L^AL^AL^BL^B$)<br>Yellow-Green ($llL^BL^B$) |
| **Leaf Perimeter Color (P)**<br>*Single Gene, Complete Dominance*<br><br>This gene stops production of pigments along the edge of the leaf, resulting in a white or yellow color where green pigment is present. | White or Yellow edge (P)<br>Solid color leaf (p) | White or yellow edges (PP or Pp)<br>Solid color leaf (p) |
| **Leaf Width (W)**<br>*Single Gene, Complete Dominance*<br><br>Presence of gene determines width of leaf and resulting shape. | Wide (W)<br>Null (w) | Wide (WW or Ww)<br>Thin/Narrow (ww) |
| **Leaf Texture (H)**<br>*Single Gene, Incomplete Dominance*<br><br>Presences of the gene results in production of small hairs on the leaf. | Hairy (H)<br>Null (h) | Dense Hairs (HH)<br>Some hairs (Hh)<br>No Hairs/Smooth (hh) |
| **Leaf Flavor (F)**<br>*Polygenic, Incomplete or Codominance*<br><br>Taste of sage is based on the production of compounds by independent genes. The fewer compounds, the less flavor.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Sage flavor ($F^T$)<br>Null (f) | Strong flavor ($F^tF^t$)<br>Light flavor ($F^tf$)<br>No flavor (ff) |
| **Scent or Aroma (A)**<br>*Polygenic, Incomplete or Codominance*<br><br>Aroma is determined by independent genes that produce oils in the leaf.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Sage ($A^T$)<br>Null (a) | Strong sage aroma ($A^TA^T$)<br>Light sage aroma ($A^Ta$)<br>No aroma (aa) |
| **Flower Color (C)**<br>*Single gene, Codominance*<br><br>Genes determine production of color pigments, alleles code for different variations of the pigment. | Blue-Purple ($C^B$)<br>Red ($C^R$)<br>Null (c) | Dark Blue Purple ($C^BC^B$)<br>Purple ($C^BC^R$)<br>Red ($C^RC^R$)<br>Light Blue Purple ($C^Bc$)<br>Light Pink ($C^Rc$)<br>White—no pigment (cc) |
| **Growth Habit (G)**<br>*Polygenic, Complete Dominance*<br><br>These genes determine into what general shape the sage grows. | Creeping or spreading (C)<br>Bush or erect (B)<br>Null (b) or (c) | Creeping (CCbb, CCBb or CcBb)<br>Bush (ccBB or ccBb ) |

# Trait Menu: Thyme

***Genus Thymus***

| Trait Profile | Alleles | Phenotype/Genotype |
|---|---|---|
| **Leaf Color (L)**<br>*Polygenic, Incomplete or Codominance*<br><br>Each gene independently controls production of a leaf pigment, so resulting leaf color may be a blend of pigments.<br><br>Note: There are many genes and resulting pigments not listed in this table and can be tetraploidy (4 chromosomes). | Blue Green ($L^A$)<br>Yellow-Green ($L^B$)<br>Null (l) | Dark Blue-Green ($L^AL^All$)<br>Light Blue-Green ($L^Alll$)<br>Sap Green ($L^AL^AL^BL^B$)<br>Yellow-Green ($llL^BL^B$) |
| **Leaf Perimeter Color (P)**<br>*Single Gene, Complete Dominance*<br><br>This gene stops production of pigments along the edge of the leaf, resulting in a white or yellow color where green pigment is present. | Perimeter color (P)<br>Null (p) | White or yellow edges (PP or Pp)<br>Solid color leaf (p) |
| **Leaf Edge or Margin (E)**<br>*Single Gene, Complete Dominance*<br><br>Presence of this gene programs cell death to produce a serrated edge. | Serrated (E)<br>Null (e) | Serrated (EE or Ee)<br>Smooth (ee) |
| **Leaf Width (W)**<br>*Single Gene, Complete Dominance*<br><br>Presence of gene determines width of leaf and resulting shape. | Wide (W)<br>Null (w) | Wide (WW or Ww)<br>Thin (ww) |
| **Leaf Texture (H)**<br>*Single Gene, Incomplete Dominance*<br><br>Presences of the gene results in production of small hairs on the leaf. | Hairy (H)<br>Null (h) | Dense Hairs (HH)<br>Some hairs (Hh)<br>No Hairs/smooth (hh) |
| **Leaf Flavor (F)**<br>*Polygenic, Incomplete or Codominance*<br><br>Taste of thyme is based on the production of compounds by independent genes. The fewer compounds, the less flavor.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. Also, genes combine for a spectrum of flavors, and are tetraploidy (4 chromosomes). A strong lemon thyme flavor might be ($F^TF^TF^LF^L$) while a light lemon thyme flavor might be ($F^TF^TF^Lf$). | Thyme ($F^T$)<br>Chocolate/Bitter ($F^B$)<br>Spicy/Cinnamon ($F^C$)<br>Lemon/Sour ($F^L$)<br>Null (f) | Strong thyme ($F^TF^T$)<br>Light thyme ($F^Tf$)<br>Very Bitter ($F^BF^B$)<br>Light bitter ($F^Bf$)<br>Strong spice ($F^CF^C$)<br>Light spice ($F^Cf$)<br>Strong sour ($F^LF^L$)<br>Light sour ($F^Lf$)<br>Flavor not present (ff) |
| **Scent or Aroma (A)**<br>*Polygenic, Incomplete or Codominance*<br><br>Aroma is determined by independent genes that produce oils in the leaf.<br><br>Note: This trait exhibits complex behavior, simplified for this exercise. | Thyme ($A^T$)<br>Lemon ($A^L$)<br>Null (a) | Strong thyme aroma ($A^TA^T$)<br>Light thyme aroma ($A^Ta$)<br>Strong lemon aroma ($A^LA^L$)<br>Light lemon aroma ($A^La$)<br>No smell (aa) |
| **Flower Color (C)**<br>*Single gene, Codominance*<br><br>Genes determine production of color pigments, alleles code for different variations of the pigment. | Blue-Purple ($C^B$)<br>Red ($C^R$)<br>Null (c) | Dark Blue Purple ($C^BC^B$)<br>Purple ($C^BC^R$)<br>Red ($C^RC^R$)<br>Light Blue Purple ($C^Bc$)<br>Light Pink ($C^Rc$)<br>White—no pigment (cc) |
| **Growth Habit (G)**<br>*Polygenic, Complete Dominance*<br><br>These genes determine into what general shape the thyme grows. | Creeping or spreading (C)<br>Bush or erect (B)<br>Null (b) or (c) | Creeping (CCbb, CCBb or CcBb)<br>Bush (ccBB or ccBb ) |

# You are a plant breeder.

A good friend who runs a local farm would like to offer a new variety of edible plant at the local market. In return, she has offered you a handsome payment and free produce for life if you can come up with a new crop to sell at her stall.

## What kind of edible plant will you breed?

*Which plant are you considering creating a new variety for? At the Museum, circle which choice you are continuing the project on.*

First Choice:

Second Choice:

## Observations

*Find the available varieties of your chosen plant in the Edible Garden and choose two to closely observe. Be sure to record what varieties they are. Consider size, growth pattern, appearance and aroma. If you cannot decide on two at this time, you may record observations for more on a separate piece of paper, but use only two to continue the project.*

**Variety 1:**

**Variety 2:**

What traits do you find desirable or undesirable in this plant?

Above, circle two traits you are going try and emphasize or eliminate. Describe your goal result:

| Desired | Undesired |
| --- | --- |
| | |

Why do you think a variety like this will be valuable?

## Breed for your variety

*Knowing what you want out of your plant and the qualities of the existing varieties, you are going to crossbreed to try and create your new variety. Use a Trait Menu to help you complete this portion of the project.*

Based on your observations, what are the possible genotypes of the two varieties that will be your parent plants? Include all possible genotypes for the resulting phenotype, then circle the genotype you are using as the parent.

**Parent Genotypes**
Use these genotypes to perform a F1 and F2 (two generations) of test crosses to 'breed' your plants. Adjacent to each test cross, list the resulting genotypes and phenotypes of the offspring in each generation. You may use extra paper if necessary.

**F1 Generation Test Cross**
*Put a star next to the resulting offspring you will be using in the F2 generation*

**F2 Generation Test Cross**

## Results of your breeding

| Description of trait/phenotype *E.g. strong lemony aroma* | Name of Variety 1: | Name of Variety 2: |
|---|---|---|
| | | |
| | | |

*Consider the results of your plant breeding. You may choose to use additional paper if necessary*

1. Were you able to produce any offspring that exhibited the changes you wanted in the plant? What was the success rate? (i.e. how many offspring exhibited these traits, how many did not?)

2. Would your final generation be able to repeatedly produce reliable offspring to maintain the new traits in following generations? Why or why not?

3. You probably had to make assumptions about the genotype of your parents. What would be the impact on your offspring if you had chosen an alternate phenotype? Would have been closer or farther away from your goal?

4. Were there offspring with surprising traits? i.e. a combination of traits that were unintended, but exhibited valuable or unwanted phenotypes? Describe what they were and explain why they might be valuable or unwanted.