BIOTECHNOLOGY

Genetic improvement method: selective breeding

Focus questions	How are breeding techniques being used in agriculture to solve problems? What are the advantages of selective breeding (artificial selection)? How does selective breeding differ from genetic modification?
Learning target	Students use candy as a model to show random selection and artificial selection, then compare the results.
Vocabulary	Genetics, trait, artificial selection, genetic modification, antibiosis, antixenosis, tolerance

HS-ESS-3: Earth and Human Activity

Performance expectation HS-ESS3-4	**Classroom connection:** Students are given three traits of soybeans and challenged to make the most aphid-resistant soybeans, then construct an explanation of the best way to obtain offspring with the aphid-resistant traits. They are asked to describe the potential impact of selective breeding on the ecosystem of a field.

Science and engineering practices

Constructing Explanations and Designing Solutions	**Classroom connection:** Students construct an explanation of the best way to obtain offspring with aphid-resistant traits.
Developing and Using Models	**Classroom connection:** Students use candy as a model to understand genetic processes.

Disciplinary core ideas

LS4.B Natural selection **LS4.C Adaptation** **ESS3.4 Human impacts**	**Classroom connection:** Students understand that selective breeding takes advantage of traits naturally found in plants chosen by humans to breed and create new adaptations.

Cross-cutting concepts

Stability and Change **Structure and Function**	**Classroom connection:** Students recognize that pest populations and resistance patterns change over time. Students connect *Rag* gene structure to function (antibiosis, antixenosis, tolerance).

This lesson is one in a series that describes genetic improvement methods. The lessons can be used as a group to compare the methods once all are completed or each lesson can be used to provide a new lens to teach a familiar concept.

Background

Humans have been selectively breeding animals and plants for thousands of years, choosing the ones with the most favorable characteristics and breeding them to achieve beneficial results. Look around at the various dog breeds that have resulted from domesticating wolves, or watch the video "Popped Secret: The Mysterious Origin of Corn" at **hhmi.org/biointeractive/popped-secret-mysterious-origin-corn**. Up until the late 1970s, this was the only way to get desired traits, but many other traits occur due to sorting of chromosomes and crossing over that takes place during meiosis as a part of sexual reproduction. Plant breeders have been able to overcome some of these obstacles by using selective breeding to improve crop characteristics, increasing yield, making them insect resistant (i.e., *Rag* genes), providing them with a health benefit (i.e., high oleic oil called Soyleic®), and developing drought tolerance, to name a few. The soybean aphid is a pest that damages soybeans by piercing plant tissues and feeding on sap, causing yield losses of up to 25 percent or more if left untreated. During outbreaks, producers typically rely on timely insecticide applications to prevent yield loss. However, host plant resistance can reduce the need for insecticide use and increase producer profitability. A single soybean plant may express one or more of these resistance types.

- Antibiosis (plant produces a toxin or unpleasant substance when attacked) suppresses aphid growth and reproduction *(Rag1)*
- Antixenosis (i.e., a hairy leaf surface) deters aphid feeding or colonization *(Rag2)*
- Tolerance allows the plant to maintain yield despite aphid injury *(Rag3)*

Prior knowledge

- Traits have various forms that control the making of proteins which perform most cellular functions
- Changes in organisms can result from genetic changes
- Basics of meiosis: genes occur on specific chromosomes; offspring get at least one chromosome from each parent

Suggested timing

30–45 minutes

Materials

- Starburst candies in pink, yellow, red, and orange (these have no allergens and are individually wrapped): 3 per student
- Opaque cups (foam cups or colored plastic that students cannot see through): 1 per every 2 students
- Electronic device for researching information

Teacher preparation

1. Copy student lesson.
2. Count out enough candy pieces for each student in random combinations.

Procedure

1. Follow the procedure outlined on the student document.
2. Be aware of common misconceptions as students do the activity:
    - *"Selective breeding is the same as GMO":*
      clarify that selective breeding uses natural reproduction.
    - *"All offspring should have desired traits if parents do":*
      emphasize meiosis and random assortment.
    - *"Resistant plants eliminate all aphids":*
      explain that resistance reduces populations, doesn't eliminate them.
    - *"Technology either works or doesn't":*
      discuss degrees of effectiveness and context-dependency.
    - *"One solution is always best":*
      emphasize integrated approaches and trade-offs.

Differentiation

Other ways to connect with students with various needs:

- **Local community:**
    - Visit local farms or agricultural research stations that use improved crop varieties.
    - Invite a plant breeder, agricultural scientist or extension agent to discuss crop development using various techniques: selective breeding, hybridization, mutagenesis and genetic engineering.
    - Students may be assigned to photograph and document products in local stores that originated from these different methods.
- **Students with special needs:**
    - Language learners: Pair ELL students with bilingual peers or supportive partners. Offer extended time for reading and processing information. Offer alternative demonstration of understanding (draw diagrams; create photo essays).
    - Reading support: Pre-teach vocabulary with visual supports; provide audio recordings of background text.
    - Auditory learners: Use verbal explanations with visual demonstrations.
    - Visual learners: Enlarge font on worksheets and research materials (14–16 pt minimum).
- **Extra support:** Introduce vocabulary and concepts within a small group to pre-teach as needed.
- **Extensions:**
    - Research specific *Rag* genes at molecular level, analyze pyrethroid resistance data, and or design field trials using seeds with *Rag* genes.
    - Include differing numbers of each of the "traits" to see if the desired population frequency changes.

Student handout

Procedure

1. The Starburst candies in the cup represent different traits that are/are not desirable in soybeans to provide aphid resistance. Which characteristics does your soybean plant have? Circle the combination of traits you have.

Color	**Soybean trait expression**
Red (*Rag1*)	Suppresses aphid growth and reproduction
Pink (*Rag2*)	Deters aphid feeding or colonization
Yellow (*Rag3*)	Yield tolerance to aphid injury
Orange	Non-*Rag* gene

2. Combine your Starburst with those of someone else at your table. Place your six traits in the cup.
3. Shake the cup.
4. Draw out three Starburst (traits). This represents the offspring from your cross.
5. Which characteristics does your new soybean plant have? Circle the combination of traits you have.

Color	**Soybean trait expression**
Red (*Rag1*)	Suppresses aphid growth and reproduction
Pink (*Rag2*)	Deters aphid feeding or colonization
Yellow (*Rag3*)	Yield tolerance to aphid injury
Orange	Non-*Rag* gene

6. Select another soybean plant at your table that has some or all of the desired traits. Cross your plant with that plant by repeating steps 2–4. How many offspring in the class have all three of the desired traits? (Report as the number that have all three out of the total possible pairings.)

Answers will vary.

Student handout

Reflection

1. Why didn't choosing the parents result in all of the offspring having the desired traits?

There will be six candies in the cups and the probability of drawing out one of each color will be determined by the number of each color and the mixing that will take place.

2. How does meiosis affect the outcome? What are the limitations of this model?

Meiosis allows different chromosomes from the parents to end up in different gametes, one from each parent, but not all gametes will have all the same information. Unless the parents are genetically identical, the offspring will show some traits from both parents.

This model does not allow for the separation of these traits to show up on separate chromosomes (i.e. the colors represent different traits, but these traits are on different chromosomes or are influenced by multiple genes. The candies do not represent genes, just the resulting traits.).

3. How might plant breeders overcome these obstacles using genetic modification?

Research on which genes influence these traits can be done. Scientists may be able to isolate which genes and modify the genes through gene editing (CRISPR) or they may find the trait in different species, isolate, and transfer those genes to plants to give them the traits to make them aphid resistant. Keeping some plants in the field that are non resistant gives insects a refuge and allows for diversity, rather than applying pressure on all insects that may result in adaptation making the plant resistance ineffective.

4. How much might it cost (in dollars and time) to genetically modify a plant gene? What are the environmental costs and benefits?

- Dollars and time: On average, GMOs take 13 years and $130 million of research and development before coming to market. See more info about the costs at: **gmoanswers.com/ask/what-average-cost-associated- research-production-and-testing-single-genetically-modified**
- Environmental costs are: A monocrop with the same genetic modifications can be more susceptible to a disease due to the lack of genetic diversity in the crop,
- Benefits: The amount of harmful insecticides is greatly reduced since the plants make their own insect resistance.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Describes selective breeding as a technological solution	Provides explanation of selective breeding without clear genetic definition. Shows limited understanding of why offspring vary from parents. Confuses selective breeding with genetic modification.	Explains that selective breeding combines traits from parent plants through sexual reproduction. Describes that offspring inherit random combinations of traits from parents. Distinguishes between selective breeding and genetic modification.	Accurately describes the probability of inheriting a specific trait using evidence from the Starburst model. Explains why not all offspring inherit all desired traits, through the mention of meiosis. Distinguishes between selective breeding and genetic modification using specific examples.
Evaluates environmental impacts and benefits	States that resistant varieties are “better for the environment” without specific explanation. Shows limited understanding of resistance management.	Explains that resistant varieties reduce need for insecticide applications. Identifies several environmental benefits of reducing chemical use.	Identifies multiple environmental impacts of insecticide use. Explains the concept of “refuge” plants and their role in preventing rapid evolution of resistant aphids. Evaluates trade-offs between different pest management approaches.
Connects mutagenesis to agricultural innovation	Limited or no connection to food development examples.	Identifies 1–2 mutagenesis crops with basic information.	Provides detailed examples of mutagenesis crops with specific traits and benefits. Synthesizes information.

Rubric for self-assessment

Skill	Yes	No	Unsure
I constructed an explanation of the selective breeding process and the obstacles to it.			
I can identify insecticide use as a human activity that impacts natural systems.			
I can list the costs (both economic and time) and benefits of genetic modification.			
I can consider unintended consequences (virulent biotypes, genetic diversity loss) of selective breeding techniques.			
I can explain how structure and function of genes and chromosomes impacts selective breeding.			
I can explain how selective breeding and genetic modification may have an impact on natural systems.			
I understand the difference between natural and induced mutagenesis.			