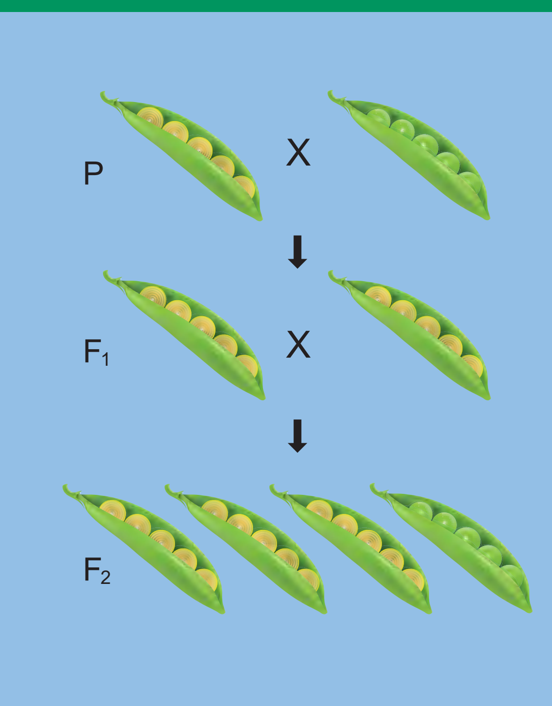
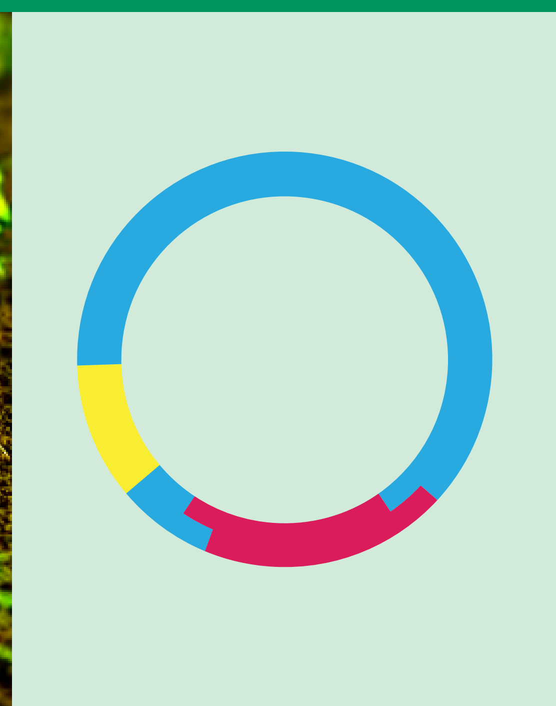
SCIENCE AND OUR FOOD SUPPLY

Exploring Food Agriculture and Biotechnology





Teacher's Guide for High School Classrooms

1st Edition

SCIENCE AND OUR FOOD SUPPLY

Exploring **Food Agriculture** and **Biotechnology**

Dear Teacher,

You may be familiar with ***Science and Our Food Supply***, the award-winning supplemental curriculum developed by the U.S. Food and Drug Administration (FDA) and the National Science Teaching Association (NSTA). It uses food as the springboard to engage students in inquiry-based, exploratory science that also promotes awareness and proper behaviors related to food safety.

FDA has developed a new component to the program: ***Science and Our Food Supply: Exploring Food Agriculture and Biotechnology*** —Teacher's Guide for High School Classrooms, 1st edition. Designed to be used separately or in conjunction with the original program, this curriculum aims to help students understand traditional agricultural methods and more recent technologies that many farmers use today.

The United States has long benefited from a successful agriculture system. However, with fewer people working on farms today compared to 100, or even 50, years ago, many American students do not fully understand how agriculture directly affects such aspects of their lives as food, health, lifestyles, and the environment. This new curriculum introduces science-based agricultural concepts of crop characteristics, planning, and selection. It also covers aspects of biotechnology that are used in agriculture today. Designed for use by high school teachers, the emphasis is on an inquiry approach that is adaptable to science, agriculture, and related classes. It also aligns with current education standards and supports educators seeking Science, Technology, Engineering, and Mathematics (STEM) activities for their classrooms.

We are confident that this new curriculum will be a useful guide for learning key science concepts about food agriculture and increasing awareness of modern food choices.

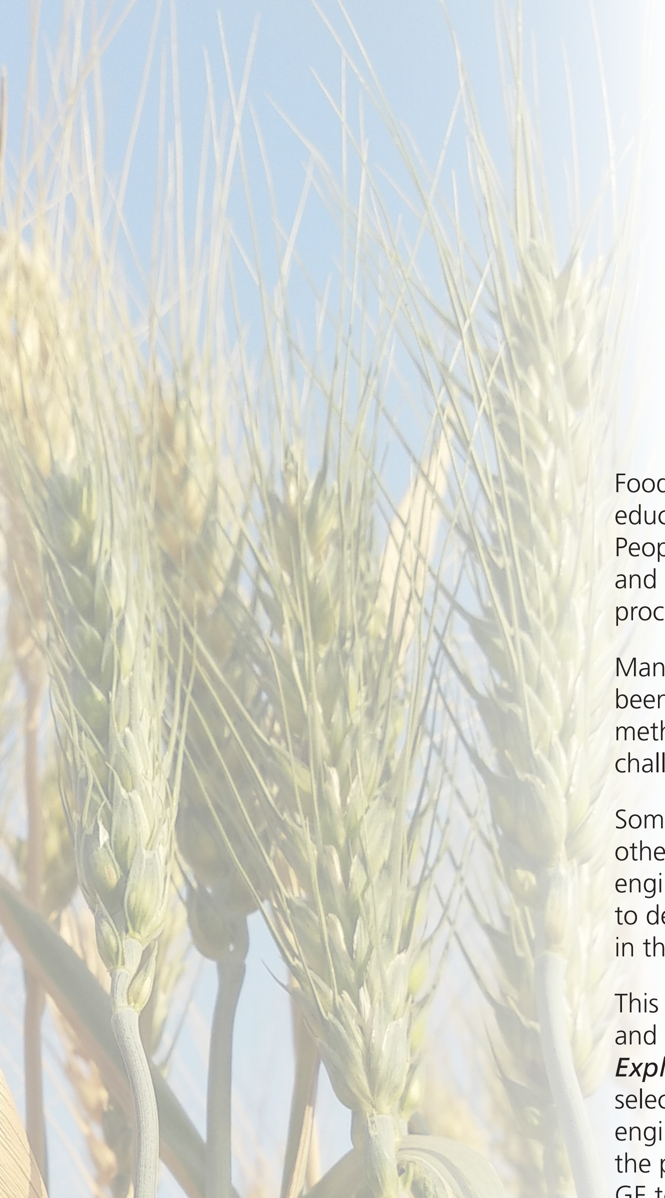
The *Science and Our Food Supply* Team

FDA – an agency of the U.S. Government that is authorized by Congress to inspect, test, approve, and set safety standards for all food (for people and animals), except meat, poultry, processed eggs, and catfish. The agency also ensures that these products are labelled truthfully with the information people need to use them safely and properly.

Curriculum Development Advisors – teachers in the fields of agriculture, biology, environmental science, technology, and related subject areas from across the United States.

TABLE OF CONTENTS

The web links provided in *Science and Our Food Supply: Exploring Food Agriculture and Biotechnology* were current at the time of publication. In the event that they change and/or are no longer available, we suggest that you visit the "home page" of the named organization. From there, search for topical information.



WELCOME TO

SCIENCE AND OUR FOOD SUPPLY

Exploring **Food Agriculture** and **Biotechnology**

Food agriculture is a topic of great interest to farmers, consumers, scientists, educators, and many people of all ages. After all, all people and animals eat. People also use different words to describe how and where their food is grown and produced. This guide provides an introduction to some terminology and processes of food agriculture.

Many methods exist to grow food products. Some of these methods have been used since plants were first domesticated, and others were added as new methods and technologies were identified to address environmental and other challenges.

Some terms used in agriculture are clearly defined (e.g., grafting) whereas other terms (e.g., agricultural biotechnology, genetically modified, and genetic engineering [GE]) may differ in how they are used. Some of the language used to describe modern agricultural techniques is also evolving. The definitions used in this Guide are for the purposes of this curriculum.

This Guide will help you inform your students about historical agriculture and modern agricultural biotechnology. The ***Science and Our Food Supply: Exploring Food Agriculture and Biotechnology*** curriculum introduces selective breeding and a subset of techniques commonly referred to as genetic engineering. [Some may also refer to this technique as genetic modification and the products of such modifications as genetically modified organisms (GMOs)]. GE techniques allow scientists to specifically modify DNA of a microorganism, plant, or animal in order to achieve a desired trait. For example, genetic engineering can be used to add one or more genes to an organism to confer a trait the organism does not have or to modify a trait already existing in the organism (increasing or decreasing the expression of a particular trait).

Expanding This Conversation

This curriculum was developed for teachers to enable students' understanding through scientific content, labs, activities, and interactive discussion in a classroom setting. You and your students may also want to discuss these topics with family, friends, and others. There is an array of information about food produced from GE sources, and some of it may be confusing or conflicting. FDA has developed a new public education initiative FEED YOUR MIND (**www.fda.gov/feedyourmind**) for general consumers to learn about this topic. You and your students might find this material helpful to share with others.

You'll find in-depth information and activities that cover these important topics:

- Selective breeding
- DNA in food crops
- An inside look at GE methods, including:
  - Bacterial transformation
  - CRISPR: a cutting-edge genome editing technique
- The environmental challenges and impacts of growing crops
- How food from GE plants is evaluated for food safety and nutrition
- Current labeling for food containing ingredients from GE plants
- Approaches to developing healthy food crops for countries with high rates of malnourishment

WHY TEACH AGRICULTURAL BIOTECHNOLOGY

Safe and nutritious food is the foundation of good health, and people in the United States have more food choices than ever before. Several of these choices are due to continuously improving technologies in food agriculture. Many people want to know more about how their food is produced so they can make the right choices for themselves. ***Science and Our Food Supply: Exploring Food Agriculture and Biotechnology*** aims to empower you and your students to make those choices. It incorporates key scientific knowledge and education resources to help students understand how biotechnology is used to produce food for humans and animals.

Food agriculture is both local and global, and students today can consider a wide range of possible careers in agriculture and related scientific fields. People with diverse agriculture or biotechnology jobs nationwide and around your community can visit your classroom, help students understand their work, and inspire some of them to have related careers of their own. Today's students are needed to help find new ways to feed our growing world.

FDA regulates the safety of food for both humans and animals, including foods produced from GE plants. Foods from GE plants must meet the same food safety requirements as foods derived from traditionally bred plants. While foods with GE ingredients are sometimes referred to as genetically modified, genetically modified organisms (GMOs), or bioengineered, FDA considers GE to be the more precise term.

FDA and the U.S. Department of Agriculture (USDA) work together to help clarify different terms related to modern food biotechnology and how to best inform consumers about food they choose to grow, purchase, and consume. In 2018, USDA released requirements for how certain foods made with agricultural biotechnology methods should be labeled.

HIGHLIGHTS OF YOUR TEACHER'S GUIDE

What's Inside . . .

Background Information for teachers introduces key concepts and the agricultural context for each module or activity. Teachers should decide how much of this information is appropriate to share with their students.

Activities engage students with hands-on exploration.

Student Worksheets are reproducible handouts for students to record their data.

Resources list online references and materials supporting each activity. Visit **www.fda.gov/teachsciencewithfood** for more online resources.

Connections to Curriculum Standards

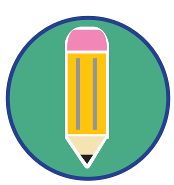
This curriculum links to national education standards that provide guidance regarding the content that should be taught at particular levels, and what students at each level should be able to do and to understand. **See pages 110-116**.

You should carefully examine local and state frameworks and curriculum guides to determine the best method for integrating ***Science and Our Food Supply: Exploring Food Agriculture and Biotechnology*** into the program(s) of your school. Appropriate placement within the scope and sequence of a school's curriculum will optimize the interdisciplinary connections and enhance the ability of a student to learn key concepts related to agricultural biotechnology.

Credible Sources: Some activities in this curriculum ask students to research available information on a specific topic. For these activities, students should use credible information sources. A Credible Source Guide is on page 94.

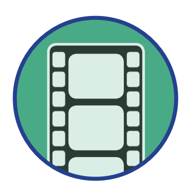
Watch for the following icons . . .

Background Information
Indicates background information



Activity
Indicates an activity

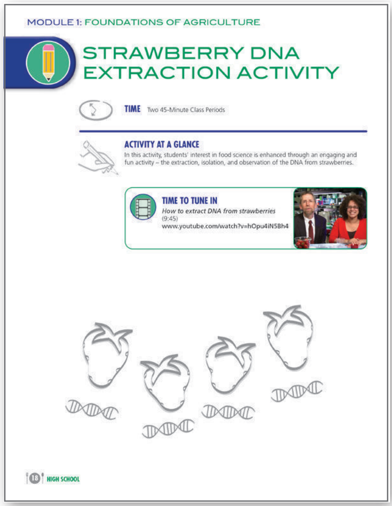
Lab
Indicates a lab



Video
Show or review a video clip

OVERVIEW OF ACTIVITIES

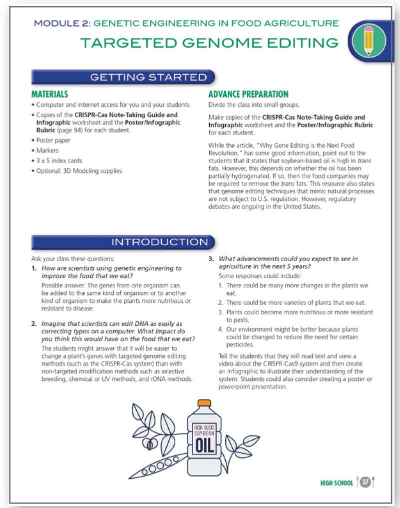
The activities are written in this easy-to-understand format.



TIME: The approximate amount of time needed to perform the activity.

ACTIVITY AT A GLANCE: Briefly summarizes the activity.

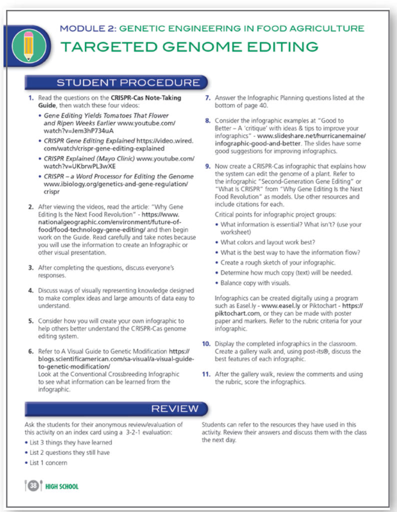
TIME TO TUNE IN: Shows the URL for an online video related to that activity.



MATERIALS: Includes the items needed to perform the activity.

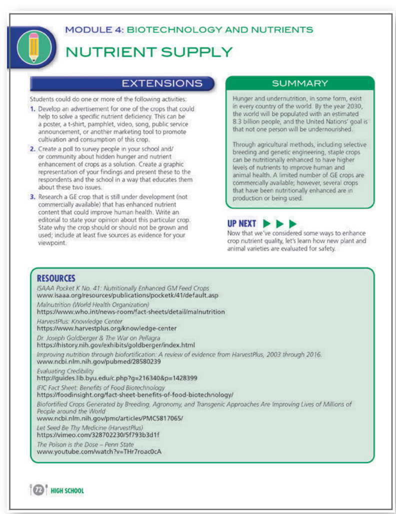
ADVANCE PREPARATION: Indicates what you need to do before conducting the activity.

INTRODUCTION: Provides fun, innovative suggestions for introducing the activity. Where provided, suggested teacher dialogue is indicated by ***boldface italics***.



STUDENT PROCEDURE: Gives the step-by-step process for the activity.

REVIEW: Uses interesting questions to guide students through a review of what they learned in the activity.



SUMMARY: Summarizes key concepts learned in the activity.

EXTENSIONS: Suggest activities to help students learn more about the topic.

RESOURCES: Provide references to online resources for the activity or for further study.

UP NEXT: Gives a preview of the next activity.

MODULE 1

FOUNDATIONS OF AGRICULTURE

This module introduces a brief overview of plant domestication, selective breeding, and other agricultural science.

For this module, it is recommended that teachers will have already taught students the following underlying key concepts: cell structure and function; cell division, cellular reproduction, and protein synthesis; plant structures, functions, and life cycles; and basic genetic terminology.

BACKGROUND INFORMATION

This section provides an overview of key stages of plant domestication and early genetic discoveries.

ACTIVITY & LAB

The Making of a New Apple Cultivar activity helps students examine traits chosen by selective breeding using the Cosmic Crisp® apple and its parent apples.

Time to Tune In

This short video shows some techniques (e.g., grafting, pest control) that one farm uses to grow and maintain an apple orchard.

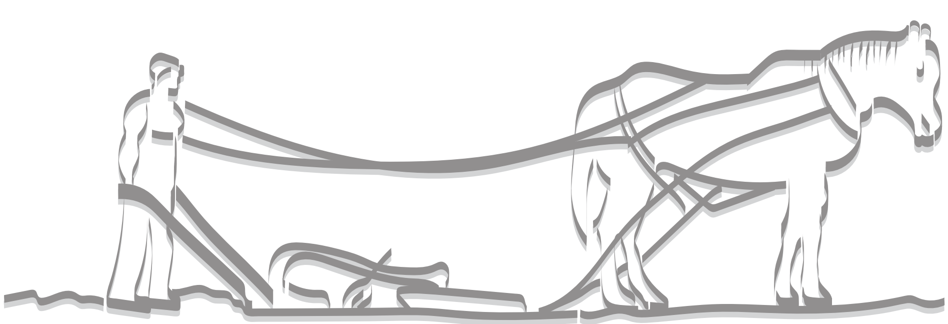
APPLE – How Does It Grow? (5:32)
www.youtube.com/watch?v=UWLmEh1HIBw

Strawberry DNA Extraction lab shows that DNA is found in a commonly consumed fruit, just as it is in food from any living source.

Time to Tune In

In this video, Drs. Eric Green and Carla Easter from the National Human Genome Research Institute of the National Institutes of Health demonstrate how to extract DNA from strawberries using everyday household items.

How to extract DNA from strawberries (9:45)
www.youtube.com/watch?v=hOpu4iN5Bh4



BACKGROUND INFORMATION

PART 1

Early Agriculture

There is clear evidence of early, small-scale farming in the Middle East about 23,000 years ago. The seeds of edible cereals, such as wild emmer, wild barley, and wild oats, along with a grinding slab and sickle blades indicate that early humans harvested cereal along the Sea of Galilee. Low-oxygen lake sediment preserved the early farming evidence for modern archaeologists to study today.

Although exact years are not defined, early agriculture began independently in several areas around the globe.

Different societies selected plants to meet their needs and preferences. Preferred plants could grow to provide sufficient quantities and survive regional climate conditions, including temperature, water availability, and sunlight. Plants that were adapted to local ecosystems and soil were (and still are) most likely to thrive and produce more food for people and livestock.

Civilization progressed through the Middle Ages and across the continents. Intercontinental exchanges after 1492 led to the global distribution of many crops. By the 1850s, railroad expansion supported both U.S. settlement and farming distribution across the country. Irrigation, crop rotation, and fertilizer use also enhanced farm production. With the invention of the gasoline-powered tractor in 1892, crop productivity increased significantly as this machine and others replaced much of the human labor. Recently, synthetic fertilizers and pesticides and more scientific selective breeding have further enhanced agricultural productivity. Throughout time, the goal has been to produce enough food to feed people, livestock, and pets.

Sample Milestones

Time	Region	Crop/Livestock
~ 21,000 B.C.	Levant (Eastern Mediterranean)	Wild emmer, wild barley, and wild oats
~ 9,500 B.C.	Fertile Crescent	Neolithic Founder Crops (emmer wheat, einkorn wheat, hulled barley, peas, lentils, bitter vetch, chick peas, and flax)
~11,000 – 9,000 B.C.	China	Rice, followed by mung, soy, and azuki
~ 11,000 B.C.	Mesopotamia	Pigs, followed by sheep
~ 8,500 B.C.	Turkey and Pakistan	Cattle
~ 8,000 B.C.	North America	Squash, potatoes, and beans
~ 7,000 B.C.	New Guinea	Sugarcane and some root vegetables
~ 5,000 B.C.	Sahel region of Africa	Sorghum
~ 8,000 – 5,000 B.C.	Andes of South America	Potatoes, beans, coca, llamas, alpacas, and guinea pigs
~ 8,000 – 5,000 B.C.	Papua New Guinea	Bananas
~ 4,000 B.C.	Mesoamerica (current Central America)	Maize (teosinte)
~ 3,600 B.C.	Peru	Cotton
~ 3,000 B.C.	Somalia and Arabia	Camels

BACKGROUND INFORMATION

Scientific Advances in Agriculture

Humans have been modifying plants for thousands of years through selective breeding. By saving seeds from plants with the traits they desired, indigenous people played a significant role in domestication of corn with a range of colors, sizes, and uses. As farmers learned more about trait inheritance, they deliberately crossbred and selected plants to improve yield, flavor, and other desirable characteristics.

In 1866, Gregor Mendel published his work on the inheritance of pea plant traits. He grew more than 10,000 plants over 8 years and tracked them by number and offspring. He was the first person to identify that traits can be either dominant or recessive. His work went mostly unnoticed for three decades, but it is considered the beginning of modern genetics.

Refresher: Mendelian Laws of Inheritance

1) *The Law of Segregation*: Each inherited trait is defined by a gene pair. Parental genes are randomly separated to the sex cells so that sex cells contain only one gene of the pair. Offspring therefore inherit one genetic allele from each parent when sex cells unite in fertilization.
2) *The Law of Independent Assortment*: Genes for different traits are sorted separately from one another so that the inheritance of one trait is not dependent on the inheritance of another.
3) *The Law of Dominance*: An organism with alternate forms of a gene will express the form that is dominant.

Although Mendel published his work in 1866, it wasn't until the early 1900's that his work was recognized.

While many advances in agricultural production were historically slow, the **Green Revolution** of the 1950s and 1960s allowed for more rapid increases in food production, specifically using high-yield seed varieties and fertilizer. In the 1960s, Norman Borlaug used selective breeding to significantly increase wheat yields (from 750 kg/hectare to 3,200 kg/hectare). His model was used later for other crops.

Throughout the 20th century, more was learned about genetic inheritance. For example, the garden strawberries that consumers buy today resulted from a cross between a strawberry species native to North America and a strawberry species native to South America.

In recent decades, certain crop improvements have also resulted from modern biotechnology when targeted changes to a plant's genetic makeup give the plant a new desirable trait. The term GE refers to the genetic modification practices that utilize modern biotechnology. This technology has been used to produce a variety of crops, including some new apple varieties that resist browning associated with cuts and bruises by reducing levels of enzymes that cause browning.

DNA in Our Food

We ingest DNA when we eat a plant or animal-derived food. An average meal contains more than 90,000 miles of DNA. Our digestive enzymes break the DNA molecules into smaller molecular components just like they break down proteins, carbohydrates, and fats into smaller molecules that our bodies can use. The DNA in our food does not become our DNA: If we eat an onion, it might give us onion breath, but it won't turn us into an onion.

A Bit About Seeds

Some plants grow from seeds. A seed is a unit of reproduction that includes the genetic material and nutrients needed to start a new plant's development. Seed plants fall into two basic groups: **Gymnosperms** (do not produce flowers) and **angiosperms** (do produce flowers). The angiosperm flowers develop into fruits that contain seeds (e.g., apples, tomatoes, squash). Most of the food that humans eat comes from angiosperms. Examples of food from gymnosperms include pine nuts and ginkgo. Edible seeds (particularly cereals, legumes, and nuts) are a major source of human calories.

Some plants are grown through **vegetative reproduction** (vegetative propagation). This is a form of asexual reproduction. One form is growing a new plant from a part (a cutting) from another plant, essentially making clones. The cuttings can take root and grow into full plants.

DID YOU KNOW?

Across the world, there are more than 1,000 seed banks that protect seed varieties of food crops to safeguard agricultural diversity. The USDA National Plant Germplasm System actively preserves seeds in several U.S. vaults; the largest facility is in the Rocky Mountains at Fort Collins, Colorado. Watch ***The Seed Bank*** to learn more about this important work: https://vimeo.com/309965169 (12:24)

The largest seed bank in the world is the Svalbard International Seed Vault, located in a mountain on a remote island in Norway. It stores more than 1 million seed varieties. The Svalbard Vault was established to preserve seeds that could be used to restore varieties needed for global food security after natural or human-made disasters. For this reason, it is called the "Doomsday" Vault. To learn more about the Vault, watch this video: ***A Rare Look Inside the Doomsday Seed Vault Deep In The Arctic*** www.youtube.com/watch?v=uAl8dSpkNWs (5:24)

BACKGROUND INFORMATION

A Closer Look at Apples

The earliest apples grew on wild trees in Central Asia and Western China, possibly about 2 to 10 million years ago, around the time early humans were evolving. Although there is some disagreement about who cultivated the first apple trees, most scientists agree that they were cultivated in Kazakhstan by 2,000 B.C.

DID YOU KNOW?

Apples have 17 chromosomes.

Most apples are **diploid** (have two sets of chromosomes), but some are **polyploid** (have more than two sets of homologous chromosomes).

People often tell stories of their ancestors and their traits. Through generations of offspring and migration, how did their family change? If food products could tell you their family stories, what could we learn about their ancestors and where they were raised? How did their family change over time? In the following apple activity, students will learn more about an apple that was developed through selective breeding from two different parent apple varieties.

Farm Facts

- Two million farms dot the U.S. landscape.
- The average farm feeds 166 people annually.
- Farm and ranch families comprise less than 2% of the U.S. population.
- One acre of land can produce different types of crops, depending on the soil type and fertility, how much rain falls, and how much the sun shines. Typically, one acre can grow:
  – 840 pounds of cotton
  – 2,784 pounds of wheat (46.4 bushels)
  – 50,000 pounds of strawberries
- There are many agriculture-related careers, including some working with animals, plants, soil, machines, water resources, environmental studies, or technology, as well as some you might not think about like being a florist or beekeeper.
- 98% of all U.S. farms are owned by individuals, family partnerships, or family corporations. Just 2% of America's farms and ranches are owned by non-family corporations.

from the American Farm Bureau Foundation for Agriculture (2019)

Agricultural Terms (for the purposes of this curriculum)

Agriculture – The science or practice of farming, derived from the Latin words "ager" (field) and "cultura" (cultivation).

Biotechnology – Specific techniques used by scientists to modify DNA or the genetic material of a microorganism, plant, or animal in order to achieve a desired trait. (Source: FDA)

Cloning (e.g., potatoes, sweet potato, sugarcane) – Producing genetically identical offspring.

Cross Breeding – Combining two sexually compatible species, breeds, or varieties to create a new variety with the desired traits of the parents. Example: The Honeycrisp apple gets its famous texture and flavor by blending the traits of the parents.

Cultivar – A contraction of "cultivated variety." It refers to a plant type within a particular cultivated species that is distinguished by one or more characters.

Domestication – The process of breeding for one or more desirable characteristics in plants and animals. This was the first step for humans to move from hunter-gatherer to agricultural societies.

Genetic Modification – The process of altering the genome of an organism. Techniques include those used in traditional breeding as well as newer modification methods like genetic engineering.

Grafting – Inserting a shoot or twig from one plant into part of another rooted plant to selectively grow a specific variety.

Heterosis (hybrid vigor) – The enhanced function of any biological quality in a hybrid offspring.

Hybridization/Hybrid – The offspring of two plants of related species or different varieties.

Precision Agriculture (PA) – An approach to farm management that uses information technology, e.g., drones and GPS data, to ensure that the plants and soil receive the exact amount of water and other nutrients for optimum health and productivity. The goal of PA is to ensure profitability, sustainability, and protection of the environment.

Selective Breeding – A breeding method that uses organisms with specific desired traits to produce the next generation. There is evidence that by 5,000 B.C. humans had some understanding of inheritance and selectively bred more useful varieties of wheat, maize, rice, and dates.

MAKING A NEW APPLE CULTIVAR

TIME Two 45-Minute Class Periods

ACTIVITY AT A GLANCE

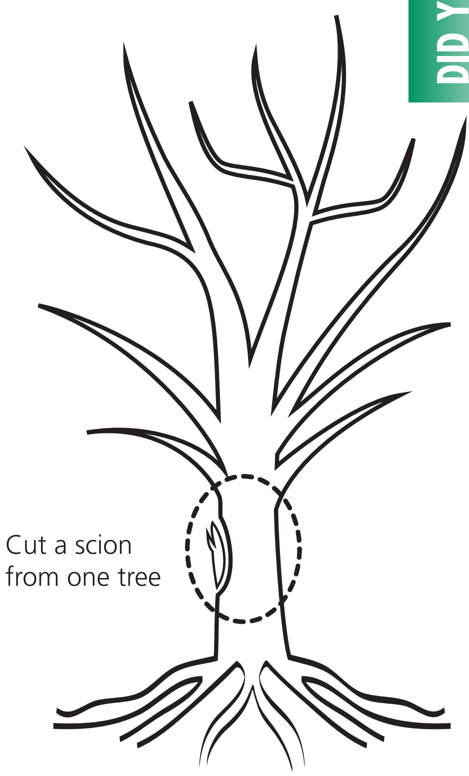
The purpose of this lesson is to introduce students to apple growing and show them how selective breeding is used to benefit both the apple grower and consumer by producing a new and better-quality apple.

TIME TO TUNE IN

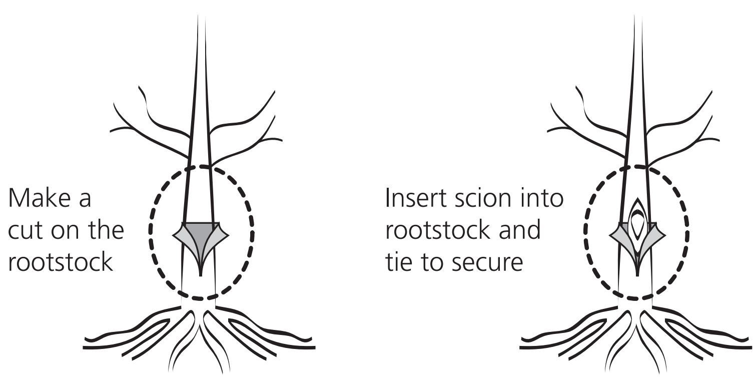
APPLE – How Does It Grow? (5:32)
www.youtube.com/watch?v=UWLmEh1HIBw

DID YOU KNOW?

Apples do not grow "true" from seed. This means that if you plant a seed from one kind of apple, the apple tree that would grow will not be the same variety as the apple that the seed came from. The only way to reproduce a specific desired apple variety is to graft a bud or cutting from a tree that previously yielded that variety onto a rootstock. A rootstock is a compatible plant that already has a healthy root system. The bud or cutting that is grafted onto the rootstock is called a **scion**.



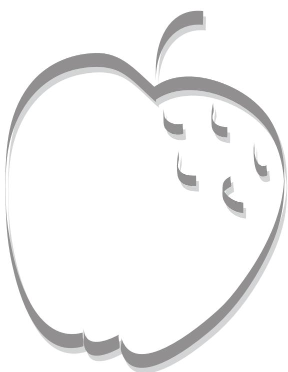
Example of a Grafting Method



BACKGROUND INFORMATION

The Development of the Cosmic Crisp® Apple

The apple is so common that it is very easy to take this fruit for granted. Yet, it has a very rich and interesting history. The wild apple trees that are thought to have come from ancient Asia thousands of years ago are believed to have produced hundreds of tiny fruits that were sour and consisted mostly of numerous dark brown seeds and a core. Over thousands of years, fruits that were more pest resistant and tolerant of geographical climate factors endured through natural selection. These apple trees were the earliest to be cultivated by humans.



Colonial America

In the United States, apples were first planted by colonists from the Massachusetts Bay Colony in the 17th century, and the first apple orchard was planted in Boston in 1625. One of our country's longest surviving apple trees was planted in 1647 in a Manhattan orchard. Unfortunately, the tree died after it was struck by a derailed train in 1866.

The only apples native to North America are crab apples, which were once called common apples. Apple **cultivars** (varieties) brought as seed from Europe were spread along North American trade routes, as well as cultivated on colonial farms. In 1845, one apple nursery catalogue offered 350 apple cultivars for sale.

Apples as a Crop

Apples are an important agricultural crop. Today, worldwide, there are more than 7,500 known apple cultivars. Over 2,500 different apple cultivars are grown in the United States, but only 100 varieties are grown commercially. Washington and New York are the leading apple-growing states. Only China produces more apples than the United States.

The basic techniques of apple-growing haven't changed much over the years; however, some new technologies, such as using DNA analysis in choosing parents and seedlings, are providing some important new tools in apple propagation. In the wild, apples can grow easily from seeds; however, since the apple fruit is formed through cross-pollination, this fruit can be very different from its parents. For this reason, apples are ordinarily propagated asexually by grafting. Grafting involves inserting a bud or twig from one plant into a small cut in the bark of a rootstock, which is a compatible trunk with established roots.

Most new apple cultivars originate as seedlings, which were either formed by chance or have been bred by deliberately crossing cultivars with promising characteristics, such as flavor and climate tolerance. The Cosmic Crisp® apple was formed by crossing the Enterprise and Honeycrisp apples. This new apple was developed over a period of 20 years by Washington State University's Tree Fruit Research and Extension Center (WSU-TFREC).

DID YOU KNOW?

Why Do Cut Apples Turn Brown? Apple cells contain phenol and phenolase enzymes. When an apple is sliced or damaged in a way that allows the cells to come into contact with air, these chemicals are exposed to oxygen, and the phenol is converted to melanin that gives apples the brown color.

BACKGROUND INFORMATION

Selective Breeding

In 1998, seed resulting from a cross between Enterprise and Honeycrisp apples was germinated and raised in a greenhouse to produce the Cosmic Crisp® apple. The seedling was transferred to a nursery and budded into a rootstock in 1999. The resulting tree was planted in an orchard in 2001. Fruit from this single, budded tree was evaluated in 2002 and 2003, and apples (now called WA 38) were selected. (Note: The WA38 designation means it was WSU's 38th attempt to get a new cultivar.) In 2004, buds from this single seedling were propagated onto rootstock. Two years later, the trees were planted in three different locations in the state of Washington. In 2007, more trees were budded for a much larger scale planting the following year. The fruit from the original tree as well as fruit from the subsequent plantings continue to be evaluated. It takes approximately 2 or more years for a new tree to bear fruit.

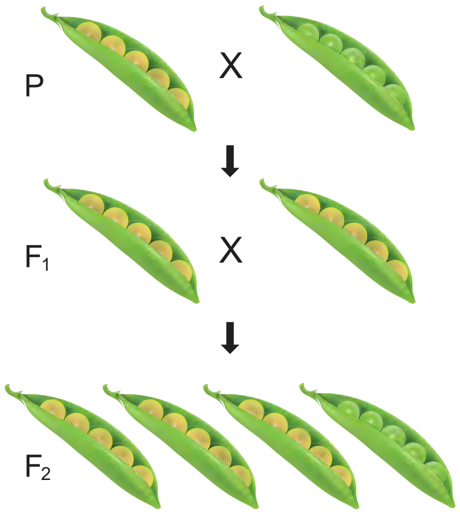
From that single seedling developed in 1998, just over 600,000 Cosmic Crisp® trees were in the ground in 2017, with some 7 million more planted in 2018 and another 6 million planned for planting in 2019. The apples became available to consumers in Fall 2019.

Genetics

The modern science of genetics began during the mid-1800s with the work of Gregor Mendel in what is now the Czech Republic. Mendel experimented with ordinary garden pea plants that were true-breeding, which means that the flowers were mostly self-pollinating, and producing offspring identical to the parents. In other words, the offspring of true-breeding tall pea plants would all be tall, and the offspring of true-breeding short pea plants would all be short. Mendel also discovered that some of the pea plant's alleles were dominant, while others were recessive. A pea plant that was a true-breed for tallness would have two alleles for tallness; and, conversely, one that was a true-breed for shortness would have two alleles for shortness.

To learn more about how traits were passed from parents to offspring, Mendel decided to cross-pollinate true-breeding tall plants with true-breeding short plants. To his surprise, all the offspring were tall. When he crossed these offspring, the plants produced were either tall or short. He observed multiple traits that had two forms, e.g., height (tall or short), pea color (green or yellow), seed shape (smooth or wrinkled). Further study of garden peas and their traits led Mendel to the conclusion that some traits have the ability to mask other traits. He called these traits dominant and those that were masked, recessive.

Pea Color Inheritance



However, in reality, not all traits behave as dominant or recessive. In some cases, the traits may express incomplete dominance where neither trait is dominant or recessive; and, the expressed trait is somewhere between the two traits. For example, some crossbred red and white flowers have pink flower offspring. In other cases, both the dominant and recessive traits may be expressed. This situation is called codominance. A sweet apple variety crossed with a tart apple variety may yield an apple variety that is both sweet and tart.

The techniques that Mendel used in the 19th century in studying genetics are still in use today.

Apple Facts

- Apples are a good source of Vitamin C, potassium, and fiber.
- Apples are fat, sodium, and cholesterol free.
- It takes the energy from approximately 50 leaves to produce one apple.
- Apples ripen 6 to 10 times faster at room temperature than if they were refrigerated.
- Apples have five seed pockets or carpels. Each pocket contains seeds. The number of seeds per carpel is determined by the vigor and health of the plant. Different varieties of apples will have different numbers of seeds.
- The science of apple growing is called **pomology**.

MAKING A NEW APPLE CULTIVAR

GETTING STARTED

MATERIALS

- **The Making of a New Apple Cultivar** worksheet – one for each student
- Internet access for each group of students.
- Optional: Actual apples from your local grocery store, depending on what is available. The *Orange Pippin* website lists places where some apples can be purchased.

ADVANCE PREPARATION

Divide the class into small groups.

Make copies of **The Making of a New Apple Cultivar** worksheet – one for each student.

Make sure students have internet access to view videos and do research.

INTRODUCTION

The United States is the world's second largest producer of apples and next to bananas, the apple is the most consumed fruit in the United States. Yet, if you ask students from where their apples come, they will have limited knowledge of the apples' source. In fact, if you mention apple, the students may think of an electronic device – not the fruit.

STUDENT PROCEDURE

1. Discuss the following questions:
   - How many different varieties of apples can you name?
   - How many of them have you eaten?
   - Which are your favorites and why?

   Think about the different traits apples have and how those traits are determined.

2. Everyone should have a copy of **The Making of a New Apple Variety** worksheet, Parts A, B & C.

3. Watch the video - *APPLE – How Does It Grow?* **www.youtube.com/watch?v=UWLmEh1HIBw**. Complete the Part A worksheet and discuss your responses. This part of the activity will help you to understand apple growing and the many different apple varieties and traits.

4. Now look at your Part B worksheet, and go to the Orange Pippin website (listed on your worksheet) for information to complete the first two columns for the Enterprise and Honeycrisp apples. Use all sections of each apple's webpage to complete the data table.

5. Be sure to:
   - analyze the data.
   - discuss the similarities and differences in the two apples.
   - record the findings in a Venn diagram (Part B Worksheet).
   - review dominant and recessive traits. Is it possible to determine whether any of the traits you have researched are either dominant or recessive?

6. The Cosmic Crisp® apple is a new, non-browning apple developed by Washington State University. This apple is the result of the selective breeding of the Enterprise and Honeycrisp™ apples. To complete the 3rd column of your Part B worksheet, use the following websites: **www.orangepippin.com** and **www.cosmiccrisp.com/the-facts**.

7. Discuss the variety of apple cultivars that have been developed; how are apples bred?

8. As you watch the following videos, complete the Part C worksheet: *Developing the Cosmic Crisp Apple*, and discuss your findings with your group.

   Why are there so many types of apples?
   www.youtube.com/watch?v=mQePz62zkqA

   Farmweek – New Apple
   www.youtube.com/watch?v=jZsu-_EGa_M.

MAKING A NEW APPLE CULTIVAR

REVIEW

Students should now understand

- the difference between dominant and recessive traits
- that creating an apple cultivar is a lengthy process
- the importance of new development to our apple supply

SUMMARY

Apples are one of the most important agricultural crops produced in the United States, and we are the second largest producer in the world. However, this production rate can be challenged by other apple-producing countries. It is important to continue to develop new apple cultivars. Apple breeders use deliberate processes to maintain an apple supply that is both grower and consumer friendly.

EXTENSIONS

Students could do one or more of the following activities:

1. Research the development of The Opal® apple, another non-browning cultivar developed at the Institute of Experimental Botany in Prague, Czech Republic. It is a cross of the Golden Delicious with the Topaz. Compare it to the Cosmic Crisp® apple.
2. Research the Arctic® apple, also a non-browning apple that was developed through genetic engineering, and compare it to the Cosmic Crisp® apple.

UP NEXT

Now that you've learned more about apple trait selection, let's take an inside look at strawberries.

RESOURCES

- *APPLE – How Does It Grow?*
  www.youtube.com/watch?v=UWLmEh1HIBw
- *Apple Varieties of the Future from WSU's Apple Breeding Program*
  www.youtube.com/watch?v=GeFCyeeDCYg
- *Cosmic Crisp® Apples*
  www.cosmiccrisp.com/the-facts
- *The Apple That Changed the World*
  www.npr.org/sections/money/2018/05/03/607384579/the-apple-that-changed-the-world; 5:56; May 3, 2018
- *Farmweek – New Apple*
  www.youtube.com/watch?v=jZsu-_EGa_M
- *Apple Tree Propagation: Grafting*
  https://apples.extension.org/apple-tree-propagation-grafting/
- *Incomplete Dominance, Codominance, Polygenic Traits, and Epistasis*
  www.youtube.com/watch?v=YJHGfbW55l0
- *Monohybrids and the Punnett Square Guinea Pigs*
  www.youtube.com/watch?v=i-0rSv6oxSY
- *Orange Pippin*
  www.orangepippin.com
- *USDA – National Apple Rootstock Breeding Program*
  https://www.ars.usda.gov/northeast-area/geneva-ny/plant-genetic-resources-unit-pgru/docs/about-pgru/national-apple-rootstock-breeding-program/
- *Why are there so many types of apples?*
  www.youtube.com/watch?v=mQePz62zkqA
- *National Agriculture in the Classroom*
  www.agclassroom.org

STUDENT WORKSHEET
MAKING A NEW APPLE CULTIVAR
PART A: *APPLE - HOW DOES IT GROW?*
www.youtube.com/watch?v=UWLmEh1HIBw

Name ______________________ Date __________ Class/Hour ________

1. What is meant by the statement "Each apple seed is genetically unique?" ______________________

____

____

2. Explain how grafting is used to propagate new apple trees. ______________________

____

____

3. Explain the importance of pollinators in the production of the apple crop. ______________________

____

____

4. Describe some methods that apple growers use to control pests? ______________________

____

____

5. If apples are only harvested in the late summer and fall, how are they available to consumers all year round? ________

____

____

6. How does the United States compare to other countries in the amount of apples produced? ______________________

____

____

STUDENT WORKSHEET

MAKING A NEW APPLE CULTIVAR

PART B: COMPARING APPLE CULTIVAR TRAITS

Name ____ Date _____________ Class/Hour __________

Refer to the following websites for this activity: www.orangepippin.com and www.cosmiccrisp.com/the-facts

	Enterprise Apple	Honeycrisp™ Apple	Cosmic Crisp® Apple
Fruit Color			
Flesh Color			
Fruit Crispness			
Fruit Size			
Fruit Browning			
Fruit Shape			
Fruit Taste			
Skin Thickness			
Use			
Disease Resistance			
Scab	____________	____________	____________
Mildew	____________	____________	____________
Fireblight	____________	____________	____________
Cedar Apple Rust	____________	____________	____________
Bitter Pit	____________	____________	____________

Make a Venn diagram to explain the similarities and differences between the Enterprise and Honeycrisp™ apples.

Using the data you have collected, is there a way to determine if any of the apples' traits are dominant or recessive?

When comparing the Cosmic Crisp® apple to the Enterprise and Honeycrisp™ apples, what do you notice about the taste of the apples? How could the inheritance of taste be explained? Are there any other traits that seem to be similarly inherited? What would you need to do to determine whether or not your ideas for inheritance are correct?

STUDENT WORKSHEET

MAKING A NEW APPLE CULTIVAR

PART C: DEVELOPING THE COSMIC CRISP® APPLE

Name ______________________________ Date ______________ Class/Hour ___________

Complete this worksheet as you watch the following two videos:

Why are there so many types of apples?
www.youtube.com/watch?v=mQePz62zkqA and
Farmweek – New Apple – www.youtube.com/watch?v=jZsu-_EGa_M

1. The Cosmic Crisp® apple was developed through selective breeding. Explain selective breeding and list the steps that apple breeders might use in this process. ______________________________

2. In researching the Cosmic Crisp®, you probably did not find information about the apple's skin thickness. What might you predict the apple's skin thickness to be? What information did you use to make this prediction? ______________

3. How long was the WA 38 (Cosmic Crisp®) cultivar in development at Washington State University? ______________

4. How do apple breeders ensure that the new apple cultivar is the same as the original seedling? ______________

5. How was the public introduction of the Cosmic Crisp® apple different than the way in which new apple cultivars are usually introduced? ______________________________

6. How do apple breeders maintain long-lasting rights over an apple cultivar? ______________________________

7. The breeders of the Cosmic Crisp® apple believe that they have produced an apple that is better than most of the other apples available today in our grocery stores. Explain why you either agree or disagree with this statement.

8. Looking to the future, what would the traits be of your "perfect" new apple cultivar? ______________________________

BACKGROUND INFORMATION

PART 2

Strawberry DNA

Deoxyribonucleic acid (DNA) is a molecule that contains the genetic instructions used in the development and functioning of all organisms and some viruses. Strands of DNA are divided into segments called genes. All organisms have genes that determine various biological traits, some of which are visible and some of which are not. Many genes, in turn, provide the information for making proteins, which carry out specific functions. This incredible molecule can easily be seen with the naked eye when collected from thousands of cells.

In this activity, students will extract strands of DNA from the nuclei of strawberry cells. Strawberry cells are used because their cells are easy to break open and they have lots of DNA. Their cells are **octoploid**, which means they have eight copies of each chromosome. Human cells are **diploid** (have two sets of chromosomes).

First, the students gently mash the strawberries to break the cells' walls and expose the inner membranes. Next the cells are mixed with the DNA extracting buffer, which is a mixture of soap, salt, and water. The soap dissolves the lipid bilayers of the cellular and nuclear membranes, exposing the DNA. The salt breaks up the protein chains that bind around the nucleic acids in the DNA. When the mixture is filtered, the strawberry cell parts that are larger than DNA are separated from the DNA. Adding chilled rubbing alcohol to the filtered solution causes the DNA to precipitate out of the solution and become visible. It is important to keep the alcohol cold, because the colder the alcohol, the less soluble the DNA. The other cell parts are soluble in the chilled alcohol.

How is DNA from Food Used by Scientists?

Scientists can use DNA isolated from food to identify particular traits, a plant or animal species, or potential contamination sources.

- Agricultural researchers use DNA analysis to choose desired traits that can be propagated in plants and animals.
- DNA barcoding is a method that tests DNA in a food source for known DNA sequences that distinguish one species from another. For example, tilapia (fish) DNA has unique sequences that differ from trout DNA, so commercial fish can be analyzed to verify correct labeling.
- Working together, the FDA and the Centers for Disease Control and Prevention can trace the origins of microbial pathogens in food that is a potential source of foodborne pathogens by using DNA samples.

Uses of Genetics in Plant Breeding

- *Backcrossing:* This is a quality control step in the selective breeding process. Because a hybrid cross can result in the inheritance of desired and unwanted traits as well as the loss of desired traits, breeders cross the offspring of hybrid crosses with the preferred parent until the offspring has the desired traits but not the unwanted traits.
- *Inbreeding:* Some plant species may be fertilized by themselves and produce an inbred variety that is identical from generation to generation. The fact that it preserves the original traits make it useful for research, as new true-breeding cultivars, and as the parents of hybrids.
- *Hybrid breeding:* Two different inbred varieties can be crossed to produce offspring with stable characteristics and hybrid vigor, where the offspring is much more productive than either parent.
- *Mutation breeding:* Mutations in a plant's genome occur naturally and can result in desirable traits. Mutation breeding is the induction of genetic mutations by exposing plant cells to radiation or certain chemicals and then selecting for plants with desirable traits.
- *Molecular marker-assisted selection:* Molecular markers are DNA sequences that 'mark' locations on a genome. Breeders use molecular markers linked to desirable traits to genetically screen and select plants for breeding.
- *Genetic engineering:* Techniques that will be covered in Module 2.

STRAWBERRY DNA EXTRACTION ACTIVITY

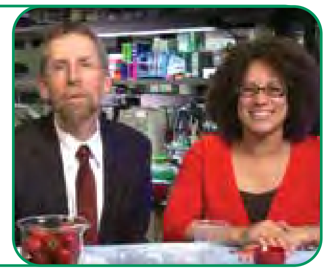
TIME Two 45-Minute Class Periods

ACTIVITY AT A GLANCE

In this activity, students' interest in food science is enhanced through an engaging and fun activity – the extraction, isolation, and observation of the DNA from strawberries.

TIME TO TUNE IN

How to extract DNA from strawberries
(9:45)
www.youtube.com/watch?v=hOpu4iN5Bh4



STRAWBERRY DNA EXTRACTION ACTIVITY

GETTING STARTED

MATERIALS FOR EACH GROUP OF TWO STUDENTS

- Isopropyl (rubbing) alcohol – approximately 10 mL
- One-cup measuring cup
- Measuring teaspoon
- Table salt (non-iodized)
- Clear dishwashing liquid
- Water
- Two eight-ounce, clear plastic cups
- Cheese cloth (or coffee filter)
- Funnel
- Three strawberries (fresh or frozen – note: frozen usually work best)
- Resealable, heavy-duty, quart-size plastic bag
- Craft stick or coffee stirrer
- Goggles for each student

ADVANCE PREPARATION

Divide the class into small groups - two is ideal for this activity.

Make a copy of the **Strawberry DNA Extraction** worksheet for each student.

Chill the isopropyl alcohol in the freezer. It is important for the alcohol to be as cold as possible. Note: If ethanol is available, it does not need to be chilled.

If preferred, you can prepare a stock extraction buffer by mixing ½ gallon (2 L) of water with ½ cup (120 mL) of clear, good quality dishwashing liquid and 2 tablespoons (30 mL) of non-iodized table salt. Slowly mix the buffer, being careful not to produce any bubbles. Too many bubbles will prevent the extraction buffer from extracting as much DNA as possible. Each group would need 10 mL of this buffer. It is best if the buffer is made at least a day ahead of time.

INTRODUCTION

Ask your students the following questions, and then discuss their responses.

What is DNA?

Where in the cell is the DNA found?

What does the word extraction mean?

How do you think you could extract the DNA from cells?

Does your food contain DNA; if so, where would that DNA be found?

The next activity will prove that the food we eat contains DNA; the DNA will be clearly visible at the end of this activity!

If students need a review of cell organelles, use a diagram of a plant cell such as the one found at this website: **https://biologydictionary.net/plant-cell/**

Laboratory Safety Reminder!

Remind students not to eat the strawberries at any time during this lab.

STRAWBERRY DNA EXTRACTION ACTIVITY

STUDENT PROCEDURE

How to extract DNA from strawberries

www.youtube.com/watch?v=hOpu4iN5Bh4

The instructions you will follow for this lab are not identical to those in the video, however seeing it done first will clarify some of the concepts.

Pick-up the materials needed for this activity and take them to your workstation; be sure that each person in your group has a **Strawberry DNA Extraction** worksheet.

Everyone must wear their goggles throughout the activity.

Instructions:

If fresh strawberries are being used, remove the green leaves.

1. Place the strawberries in the plastic bag and seal it, being careful to eliminate as much air as possible. Gently smash the berries for about two minutes; be very careful not to crush the bag. Make sure the berries are completely crushed because this starts to break open the cells and release the DNA.

2. Prepare the DNA extraction liquid by mixing together 2 teaspoons (10 mL) of detergent, 1 teaspoon of salt, and ½ cup (100 mL) of water in one of the plastic cups. Stir the mixture very carefully so there are no bubbles; the bubbles might interfere with the precipitation of the DNA.

3. Add 2 teaspoons (10 mL) of the DNA extraction liquid to the bag with the strawberries. This will further break down the membranes and release the DNA strands.

4. Reseal your plastic bags and carefully eliminate as much air as possible. Gently smash the berries for another minute; be sure to avoid creating any bubbles because they will prevent the extracting buffer from extracting as much DNA as possible.

5. Place the funnel inside the second plastic cup and place the cheese cloth inside the funnel. Open the bag and pour the strawberry mixture into the cheese cloth.

6. Twist the cheese cloth just above the liquid and gently squeeze the remaining liquid into the cup. After filtering the mixture, dispose of the cheese cloth and the plastic bag.

7. Note the level of the liquid in the cup; slowly add an equal amount of chilled rubbing alcohol to the cup, layering the alcohol on top of the strawberry liquid. This can be done by tilting the cup and slowly pouring the alcohol down the side of the cup. The DNA has just been isolated from the rest of the material contained in the cells of the strawberry.

8. Wait a few minutes and then carefully observe the line between the strawberry mixture and the alcohol. Notice development of a white, threadlike, cloud at this line. This is the strawberry DNA. The DNA will clump together and float to the top of the alcohol layer.

9. Observe the other groups' DNA samples; are there any differences?

10. Use the craft sticks or spoons to slowly extract the DNA from the cup.

11. Clean up your workstations and complete the worksheet.

STRAWBERRY DNA EXTRACTION ACTIVITY

REVIEW

Explain the importance of each step in the strawberry DNA extraction process by asking the following questions:

Why did you have to mash the strawberries?

What was the purpose of the salt in the DNA extraction solution?

What was the purpose of the soap in the DNA extraction solution?

Explain what happened in the final step when the rubbing alcohol was added to the strawberry extract.

Explain what the DNA looked like.

When the students have completed their responses to the questions, have them share their responses.

If you want to review the DNA extraction process and the purpose for each step, this video might help - *Strawberry DNA Extraction Lab Explanation* - www.youtube.com/watch?v=vnjwNiJktZk

Finally, ask the students to answer the following questions, and, when finished, share their ideas.

Why is it useful for scientists to be able to extract DNA from fruits and vegetables? List at least two reasons.

If you could extract the DNA from any fruit or vegetable, which one would you choose and why would you want to study its DNA?

SUMMARY

While this activity is a very much-simplified process, the isolation, extraction, and observation of DNA are important parts of food agricultural science, allowing scientists to accurately select for the most desirable traits for the fruits and vegetables that we eat.

EXTENSIONS

Students could do one or more of the following activities:

1. Experiment with extracting DNA from other fruits and vegetables and compare the amount of DNA extracted.
2. Perform the experiment and substitute different kinds of soaps and detergents such as powdered soaps, shampoo, or body scrubs in place of the dishwashing liquid.
3. Experiment with changing the quantity of materials used and comparing the amount of DNA extracted.
4. Watch the video – *Growing Strawberries: Strawberry Fields Forever* - www.youtube.com/watch?v=CnQgSXrYo6Q. This 4-minute video shows how California strawberry growers are learning to grow their crops using newer, high-tech tools.

RESOURCES

- *Growing Strawberries: Strawberry Fields Forever* from the CA Department of Food and Agriculture www.youtube.com/watch?v=CnQgSXrYo6Q
- *What is DNA and How Does It Work?* www.youtube.com/watch?v=zwibgNGe4aY

UP NEXT ▶ ▶ ▶

Now that you've learned about DNA in food, let's take a look at some more laboratory techniques being used to produce some plant and animal varieties.

STUDENT WORKSHEET
STRAWBERRY DNA EXTRACTION

Name ______________________________ Date ______________ Class/Hour ___________

1. What is DNA? ______________________________

____

2. Where in the cell is the DNA found? ______________________________

____

3. What does the word *extraction* mean? ______________________________

____

4. How do you think you could extract the DNA from cells? ______________________________

____

5. Does your food contain DNA, and if so, where would that DNA be found? ______________________________

____

6. Each step in the extraction process aids in isolating DNA from the other cellular materials. Explain why each step was necessary and put the DNA extraction procedure into context by answering the following questions:

   Why did you have to mash the strawberries? ______________________________

   ____

   What was the purpose of the salt in the DNA extracting solution? ______________________________

   ____

   What was the purpose of the liquid detergent in the DNA extracting solution? ______________________________

   ____

   Explain what happened when you added the alcohol to the strawberry extract. ______________________________

   ____

   What did the extracted DNA look like? ______________________________

   ____

7. Why is it useful for scientists to be able to extract DNA from fruits and vegetables? List at least two reasons. __________

____

8. If you could extract the DNA from any fruit or vegetable, which one would you choose and why would you want to study its DNA? ______________________________

____

MODULE 2 GENETIC ENGINEERING IN FOOD AGRICULTURE

This module introduces students to laboratory methods used to alter genetic material and create organisms with desired traits.

For this module, it is recommended that teachers will have already taught students the following underlying key concepts: Cell structure and function, DNA structure, DNA replication, bacterial structure (prokaryotes), basic cell division and reproduction, transcription, translation, protein expression and synthesis, and general selective breeding.

BACKGROUND INFORMATION: PART 1

Genetic Engineering introduces some key milestones in the development of tools used in the laboratory to change DNA sequences. It also highlights select genetic modification processes.

ACTIVITY

Genetic Engineering introduces students to laboratory techniques developed to change an organism's genetic material to give it a new trait.

Time to Tune In

Soybean Genetic Modification (6:30)
www.youtube.com/watch?v=wTraZwHDHXk

Herbert W. Boyer & Stanley N. Cohen (6:49)
www.youtube.com/watch?v=G3H-Uzts108

Transferring genes into plants (1:35)
www.youtube.com/watch?v=HOLaRq6ahzo

Bacterial Transformation (2:04)
https://vimeo.com/170630548

BACKGROUND INFORMATION: PART 2

Targeted Genome Editing discusses cutting-edge technology now being used to "edit" DNA.

ACTIVITY

CRISPR-Cas – A Genome Editing System allows students to explore how one technology is used to target a specific DNA locus to delete, change, or insert DNA sequences. Genome editing systems can be either transgenic or work without inserting DNA from another organism.

Time to Tune In

Gene editing yields tomatoes that flower and ripen weeks earlier (2:50)
www.youtube.com/watch?v=Jem3hP734uA

CRISPR Gene Editing Explained (2:11)
https://video.wired.com/watch/crispr-gene-editing-explained

CRISPR Explained (Mayo Clinic) (1:38)
www.youtube.com/watch?v=UKbrwPL3wXE

CRISPR – a Word Processor for Editing the Genome (6:09)
www.ibiology.org/genetics-and-gene-regulation/crispr

BACKGROUND INFORMATION

PART 1
Genetic Engineering

For most of history, farmers had to wait several plant generations before crops had the traits they most desired. The farmers used selective breeding, the process of choosing parent plants with the best traits over many generations. Selective breeding resulted in dramatic genetic changes to the species. While earlier farmers had no concept of the science of genetics, selective breeding based on observable traits allowed them to use plants' DNA to solve agricultural challenges and to improve the food supply. This approach to selecting specific traits is exemplified by the apple activity in Module 1.

Although selective breeding is still widely used, there are more modern processes available to alter the genetics of microorganisms, plants, and animals. More modern techniques to alter an organism's genetics includes mutation breeding, molecular marker-assisted breeding, genetic engineering, and genome editing.

Genetic engineering (GE) refers to deliberately modifying the characteristics of an organism by altering its genetic material. GE techniques include particle bombardment, Agrobacterium-mediated transformation, and targeted genome editing (the most recent additions to the genetic engineer's toolbox). Using GE technology, scientists can bring us improved agricultural products and practices faster than in the past.

Why genetically engineer plants?

Plants are genetically engineered for many of the same reasons that selective breeding is used: Better nutrition, higher **crop yield** (output), greater resistance to insect damage, and immunity to plant diseases.

Selective breeding techniques involve repeatedly cross-breeding plants until the breeder identifies offspring that have inherited the genes responsible for the desired combination of traits. However, this method may also result in the inheritance of unwanted genes responsible for unwanted traits (called **linkage drag**), and it can result in the loss of desired traits.

Key biotechnology events related to food agriculture

1901	Japanese biologist Shigetane Ishiwatari discovered *Bacillus thuringiensis* (Bt), which makes a natural pesticide, found in soil worldwide and used by farmers since the 1920s.
1919	Karoly Ereky introduced the new term *biotechnology* (i.e., using biological systems to create products).
1971	Paul Berg completed a landmark gene splicing experiment.
1973	Stanley Cohen and Herbert Boyer created the first modified organism using recombinant DNA (rDNA) technology.
1974	Rudolf Jaenisch and Beatrice Mintz created the first transgenic animal (a mouse).
1978	Herbert Boyer starts a new company, Genentec and produces recombinant insulin.
1983	Mary-Dell Chilton inserted an antibiotic-resistant gene into a tobacco plant creating the first GE plant.
1987	Calgene creates the FlavrSavr® tomato.
1989	Chymosin from GE microorganisms authorized as a food processing aid by FDA.
1994	FDA concludes the FlavrSavr® tomato is as safe as comparable non-GE tomatoes.
1995	EPA approves the use of a Bt toxin as a plant-incorporated pesticide in a GE crop.
1998	GE virus-resistant papaya was grown commercially in Hawaii.
2012	CRISPR-Cas9 is used as a programmable RNA-guided DNA cutting tool.
2015	Genetically modified salmon is the first GE animal approved for food use in the United States.
2017	GE apples are available for sale in the United States.
2019	FDA completes consultation of high oleic soybean oil, first food from a genome edited plant.

GE techniques can be used to isolate a gene or genes for the desired trait, add a gene from another organism or edit chromosomal DNA in a single plant cell, and generate a new plant with the trait from that cell. By adding one desired gene from the donor organism or by editing the gene in the chromosomal DNA of the single cell, the unwanted traits

BACKGROUND INFORMATION

from the donor's other genes can be excluded. GE is used in conjunction with selective breeding to produce GE plant varieties that are on the market today.

Advanced Content

GE techniques can be used to add new DNA to code for the expression of a new protein or to suppress expression of a native plant protein. Protein suppression can be achieved though transcriptional or post-transcriptional gene silencing (PTGS). **RNA interference (RNAi)** is a form of PTGS that targets mRNA transcripts for cleavage, preventing their translation into protein. The two different ways to achieve a desired trait are important, because both have been used to create GE plants that are used in food today.

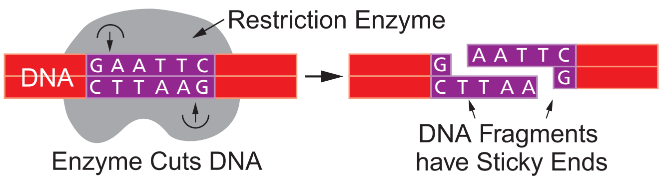
Development of GE Tools in Bacteria

Throughout the past 100 years, several developments have led to current GE methods. After early geneticists were able to identify the gene locus for specific plant traits, various methods were used to try to transfer the specific DNA sequence from one plant to another. One method was injecting the DNA from the donor plant directly into the recipient plant cell to see if it would integrate into the recipient cell's genome. Unfortunately, the DNA was degraded, and the method was unsuccessful. It was like trying to send an envelope through the mail with only a zip code; the postal service wouldn't know where to deliver it. Scientists eventually used bacteria to transfer new DNA to the recipient plant cell.

Transformation is the changing of the cell's genetic makeup through the addition of new DNA. The DNA can come from the environment surrounding the cell via "**horizontal gene transfer**" or be added in a laboratory through GE methods. The laboratory method developed to combine genetic sequences that would not otherwise be found in the genome is called **recombinant DNA (rDNA)** technology.

In 1973, Herbert Boyer and Stanley Cohen produced the first successful GE organism. Boyer had expertise using **restriction endonucleases** (enzymes that cut DNA at specific nucleotide sequences), and Cohen studied **plasmids** (small rings of DNA) in bacteria. They were able to use a restriction enzyme to cut open a plasmid loop from one bacterial species, insert a gene from a different bacterial species, and close the plasmid, which combined the genes from different bacteria into one rDNA molecule. An enzyme called ligase was used to help join the cut DNA strand. Then they transformed this rDNA plasmid into the bacterium *Escherichia coli (E. coli)* and showed that the bacteria could utilize the rDNA. In Boyer and Cohen's experiment, one gene coded for tetracycline resistance and the other for kanamycin resistance. Tetracycline and kanamycin are antibiotics that kill bacteria that do not have resistance genes. It was possible to see which of the *E. coli* in their experiment had successfully acquired the new genes by culturing them in the presence of the antibiotics, where only the successfully transformed bacteria could grow. These experiments showed that bacterial transformation could be used to deliver the desired DNA to a useful site, just as the postal service delivers mail to the correct address.

Restriction enzymes are like scissors that cut DNA at specific sequences. Some restriction enzymes leave blunt DNA ends while others leave short, single-stranded overhangs called sticky ends.



Ligase enzymes are like the glue or tape for connecting DNA sequences in GE, or molecular biology, procedures.

Bacterial transformation still serves as the basis for a number of DNA technologies. Bacteria are used extensively in the laboratory for rDNA research. There are even some species of bacteria that go through the transformation process naturally, but most bacteria needs manipulation to become **competent** (able to take up the plasmid). Using the techniques from bacterial transformation, scientists have learned how to change the genome of plants, including plants that we use for food.

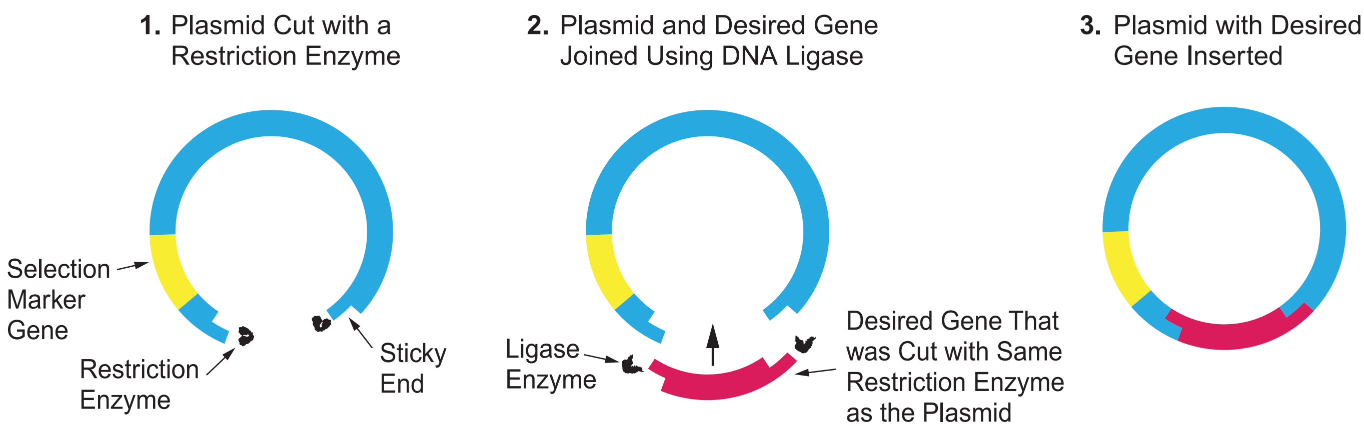
Scientists worldwide continue to use the Boyer and Cohen techniques to improve GE tools that develop, modify, and improve consumer products, including many of the food products we eat.

Nature's Own Genetic Engineer

A widely used method of transferring a transgene to a plant is to use the soil bacterium *Agrobacterium tumefaciens* (*A. tumefaciens*). This bacterium has a natural ability to enter a plant cell and insert its own DNA into a plant's genome. A plasmid is constructed to include *A. tumefaciens* genes needed for transferring DNA into the recipient plant cell, the transgene of interest, and a selectible marker, such as a gene conferring antibiotic-resistance or herbicide tolerance. Scientists now use the bacterium's natural behavior to insert the transgene into a plant's genome.

BACKGROUND INFORMATION

Simplified Steps of Plasmid Development



Application of GE Tools in Plants

Plants can be genetically engineered to be resistant to pests and herbicides, to increase crop yield, or to tolerate adverse weather conditions using a process similar to bacterial transformation. Plants can also be engineered to produce fruits and vegetables that have longer and more stable shelf-lives in the grocery store. These GE uses have potential trickle-down benefits from the farmer to consumers, animals, and the environment. Because plants are eukaryotic and contain a nucleus, a slightly different method than the one used for bacterial transformation is used to insert the gene of interest.

For example, if scientists find a gene for enhanced drought resistance in a plant, and they want to use the gene to make another plant more drought resistant, an advantage of GE over selective breeding is that less time is required and linkage drag is avoided. The desired gene to be transferred and added to the genome of the recipient plant is often referred to as a **transgene**.

Genetic Engineering

- Allows the direct transfer of one or just a few genes between either closely or distantly related organisms
- Achieves crop improvement in a shorter time compared to conventional breeding
- Allows plants to be modified by adding, removing, or switching off particular genes

Adapted from: Agricultural Biotechnology (A Lot More than Just GM Crops).
www.isaaa.org/resources/publications/agricultural_biotechnology/download/Agricultural_Biotechnology.pdf

The technologies used to clone or synthesize genes are changing and evolving. The three major methods currently used are:

- Traditional cloning – isolating DNA directly from the genome of the donor organism and inserting it into a plasmid for later use
- Subcloning the gene of interest – copying the gene from an existing collection of DNA clones ("DNA library")
- *De novo* gene synthesis – building a gene from scratch, using single nucleotides or short oligonucleotide strands without the need for a physical template

The techniques used by scientists to assemble and insert DNA pieces into the plasmid are also evolving along with the complexity of multi-gene DNA constructs. While simple restriction enzyme protocols can be used to create a single gene insert, multi-gene constructs such as those required for complex plant traits require more complex assembly strategies.

What is a DNA Library?

A DNA library is a collection of cloned DNA fragments that are stored in plasmids, which in turn are maintained and propagated in bacterial or yeast cells. The type of library is classified by the source of the DNA and the plasmid – referred to as a cloning vector – used to construct the library. Sources of DNA may be a single cell, a tissue, an organism, or an environmental sample containing multiple organisms. The DNA may be obtained from genomic sequences or from isolated mRNA and converted to complementary DNA (cDNA). Scientists use DNA libraries to find and study DNA encoding proteins or other functions of interest.

BACKGROUND INFORMATION

General Plasmid Preparation

Bacterial plasmids are used to store a ready supply of the gene of interest. In the case of Agrobacterium-mediated plant transformation, the plasmids are used to transfer the gene of interest to the genome of the recipient plant. To receive the gene of interest, the bacterial plasmids are treated with a restriction enzyme that is compatible with the gene. This way, the plasmid DNA will have the same sticky ends as the gene, so they will combine more easily. The gene and plasmid DNA preparations are mixed with DNA ligase to seal the sticky ends of the DNA molecules together.

Scientists may also modify the bacterial plasmid using a similar process to insert one or more **selectable marker** genes. The selectable marker genes will be important later in the GE process when bacteria or plant cells with the gene of interest are being isolated. There are many selectable markers used to screen for bacterial, as well as plant transformants.

Selectable markers include:

- Auxotrophy (selects for the ability to grow on certain carbon sources)
- Antibiotic resistance (selects for ability to grow in the presence of a specific antibiotic)
- Herbicide tolerance (selects for ability to grow in the presence of a specific herbicide)

This new bacterial plasmid is called a **transformation plasmid** and has the gene of interest as well as the selectable marker gene. The transformation plasmid is added to bacteria using a bacterial transformation method. Finally, the bacteria are plated onto a medium containing the selection factor that will inhibit the growth of bacteria that did not take up the plasmid. The Petri plates are incubated to encourage bacterial growth, and only the bacteria that have taken up the transformation plasmid with the selectable marker gene will grow. Bacteria without it will not grow, resulting in millions of bacteria with the gene of interest in their DNA.

The next step is to transfer the gene to the plant cells. Currently, the most frequently used technique is Agrobacterium-mediated transformation. Bombardment with a gene gun is less common and typically used in cases where Agrobacterium-mediated methods don't work. Agrobacterium is a plant pathogen that has the natural ability to transfer DNA to plant cells. GE methods use a version of the Agrobacterium plasmid that has been "disarmed": the modified plasmid still has the ability to transfer DNA into the plant's genome, but it's disease-causing genes have been removed. Agrobacterium that have been transformed with the plasmid carrying the gene of interest and selectable marker are mixed with the plant cells. The Agrobacterium enters the plant cells and inserts a segment of the plasmid DNA (containing the gene and selectable marker gene) into the plant's genome. Once the Agrobacterium has had time to transform the plant cells, the cells are placed on medium containing: (1) An antibiotic that kills the Agrobacterium, (2) the selection factor that will inhibit growth of plant cells that did not take up the plasmid DNA, and (3) plant hormones that encourage the transformed cells to grow into new plants.

After a gene has been successfully inserted into the plant's genome, the modified plant must be able to grow and reproduce with its newly modified genome. First, the genotype of the plant must be studied so that the scientists only grow plants in which the genome has been modified correctly. When this is done, the GE plants will be grown under controlled conditions in a greenhouse and then in field trials to make sure that the new plants possess the desired new trait and show no new undesired characteristics.

Food from GE Plants

The first GE plant evaluated by the FDA for human consumption was the FlavrSavr® tomato. FDA concluded that the FlavrSavr® tomato was as safe as comparable non-GE tomatoes. It was brought to market in 1994, but it was not sufficiently profitable to continue production. Although there are currently no GE tomatoes on the market, other GE food crops are commercially available. Most of these GE plants were engineered to increase resistance to disease or pests, or tolerance to specific herbicides.

As of 2023, there were 12 food crops available in the U.S. Of these, only a few GE crops in the grocery store are available as <u>whole produce</u>. Whole produce could include certain cultivars of apple, pineapple, potato, papaya, sweet corn, squash, and tomato. Ingredients derived from GE corn, soybeans, sugar beets, and canola (such as flour, oil, starch, and sugar) are used in a wide variety of foods including cereal, corn chips, veggie burgers, and more.

> The 12 GE crops today are: Alfalfa, apples, canola, corn (field and sweet), cotton, papaya, pineapple, potatoes, soybeans, squash, sugar beets, and tomato.

Animal food: In the United States, more than 95 percent of food-producing animals consume food containing ingredients from GE crops. GE plants can also be found in food for non-food producing animals, such as cats and dogs.

ACTIVITY 1: GENETIC ENGINEERING

TIME Three 45-Minute Class Periods

ACTIVITY AT A GLANCE

In addition to selective breeding, GE tools are used by plant breeders to solve agricultural challenges, such as producing enough food to feed a growing global population, or minimizing production impacts on our environment. Plants have been engineered to be more nutritious, more resistant to pests, drought tolerant, and more robust to remain intact during packing and transport. In this activity, students will review the process of bacterial transformation and then look at the processes involved in creating GE plants.

TIME TO TUNE IN

Soybean Genetic Modification (6:30)
www.youtube.com/watch?v=wTraZwHDHXk

Herbert W. Boyer & Stanley N. Cohen (6:49)
www.youtube.com/watch?v=G3H-Uzts108

Transferring genes into plants (1:35)
www.youtube.com/watch?v=HOLaRq6ahzo

Bacterial Transformation 3D Animation (2:01)
https://vimeo.com/170630548

GETTING STARTED

MATERIALS

- Computer and internet access for the teacher and students
- **Genetic Engineering** worksheet
- Set of **The Genetic Engineering Process** cards (10 cards with illustrations and 10 cards with GE process steps). See pages 32-33.
- Mailing Labels – 10 to a sheet; 2 sheets for each set of cards
- 3″ x 5″ index cards
- Chart paper
- Double-sided tape

ADVANCE PREPARATION

1. Divide the class into small groups.
2. Make a copy of the **Genetic Engineering** worksheet for each student.
3. Make **The Genetic Engineering Process** cards. To make one set of cards, copy the 10 steps in The Genetic Engineering Process on one sheet of 2″ x 4″ mailing labels and the illustrations for those steps on another sheet of labels. Attach the labels to 3″ x 5″ index cards. You could also copy the templates on card stock. Making sets in different colors helps keep the sets together. (Make one set of cards for each group.)

   Alternatively, print the card art and text boxes using only one side of each sheet of paper, and cut the sections out for students to compare and match up.

   Remember to mix (shuffle) the cards before handing them out.

GENETIC ENGINEERING

INTRODUCTION

Genetic engineering is often misunderstood, so it is important to determine what your students understand about bacterial transformation and, especially, genetic engineering. Use the KWL (What do you **K**now? – What do you **W**ant to know? – What did you **L**earn?) strategy to begin the activity.

Ask your students what bacterial transformation means to them. Refer them to the **Genetic Engineering** worksheet and ask them to record their thoughts and questions on the chart at the top of the worksheet.

When your students have completed their responses, ask them to share their thoughts with the class. Ask if they have heard the term "genetic engineering" and, if they have, what this term means.

Have them record their ideas and questions.

These questions will help you to assess your students' current understanding, so you can address any of their misconceptions.

Throughout this activity, students should refer back to the questions and comments on their worksheet.

Note: The steps in this activity can be adjusted to match the pace and content you want to emphasize with your students. The activity could follow a vocabulary review and be used to further review vocabulary. It could also be used as a post-assessment of the module's content.

STUDENT PROCEDURE

1. Everyone should have a copy of the **Genetic Engineering** worksheet (page 31). Complete the "What do I know?" and "What do I want to know?" columns of the KWL Chart.

2. Watch the video – *Herbert W. Boyer & Stanley N. Cohen* **www.youtube.com/watch?v=G3H-Uzts108** that explains how the two scientists, Herbert Boyer and Stanley Cohen, were the first to transform bacteria. Complete the "What did I learn" column.

3. Watch the two videos – *Soybean Genetic Modification* **www.youtube.com/watch?v=wTraZwHDHXk** and *Transferring genes into plants* **www.youtube.com/watch?v=HOLaRq6ahzo**. .

   Watch the 3D Animation – *Bacterial Transformation* **https://vimeo.com/170630548**. While watching the animation, answer the questions on the **Genetic Engineering** worksheet. When the worksheet is completed, discuss your responses as a class, so that everyone has a clear understanding of the process of bacterial transformation and the terminology used in the process. Refer to your KWL Charts to make any changes.

4. In the next part of the activity, you will work with a set of cards that represents the steps in the **Genetic Engineering Process**. Your task is to put the cards in the correct procedural order. There are two parts to the card set: one has descriptions of the steps; the other has diagrams that illustrate each step.

5. Each group should have a set of the Genetic Engineering Process cards. Distribute the cards with the text descriptions of the GE steps to your group. The challenge is to put the description cards in the order that reflects the steps in the GE process. As each card is read out, discuss where in the process this step takes place. When your group thinks they have the correct order, share this with the teacher. If the order is correct, match the illustrated card to the description card. Each group member should be able to explain how the group determined the order of the cards and which illustration went with each step.

6. Once your group has successfully arranged your cards, use double-sided tape to attach the cards to a piece of chart paper. Use the charts to explain the steps in the GE process; what information on the cards helped you to put them in the right order? In your own words, describe the GE Process.

GENETIC ENGINEERING

REVIEW

Show the video that was seen at the beginning of the activity: *Herbert W. Boyer & Stanley N. Cohen* **www.youtube.com/watch?v=G3H-Uzts108.** Have students return to their KWL Charts and review their comments and questions about GE. Ask them what further questions they might have, and use these as the basis for the review, addressing any misconceptions the students still have.

SUMMARY

Genetic engineering is the use of modern techniques, including recombinant DNA methods, to modify the genetic information in an organism. It allows for faster trait selection than selective breeding, and can enhance the development of plant cultivars to help address some environmental challenges. Some anticipated changes for the future include: A larger library of genes to choose from as scientists are rapidly sequencing the genomes of organisms, and the ability to modify increasingly complex traits as scientists learn more about the cellular and molecular biology of plants.

EXTENSIONS

Students could do one or more of the following activities:

1. Conduct the Who Wants to Be a Genetic Engineer - Crop Genetic Engineering Simulation **https://mediahub.unl.edu/media/10740**
2. Create an infographic on bacterial or plant transformation.
3. Conduct online research and create a chart of crops that have a specific GE-modified trait.

RESOURCES

- *Transformation in Bacteria* www.youtube.com/watch?v=dKD19cXkWBw
- *How to Make a Genetically Modified Plant* www.youtube.com/watch?v=JtkhHIG3nx4&t=365s
- *Who Wants to Be a Genetic Engineer - Crop Genetic Engineering Simulation* www.labxchange.org/library/items/lb:LabXchange:b4d9f467:lx_simulation:1
- *Changing the Blueprints of Life - Genetic Engineering: Crash Course Engineering #38* www.youtube.com/watch?v=FY_ZUEKWhBc

UP NEXT

In the next lesson, we will study another process used to change the genome of a plant – CRISPR.

STUDENT WORKSHEET

ACTIVITY 1: GENETIC ENGINEERING

Name ____ Date _____________ Class/Hour __________

KWL CHART			
Exploration Question	**What do I know?**	**What do I want to know?**	**What did I learn?**
What is bacterial transformation?			
What is genetic engineering?			

Answer the questions below after viewing these videos: *Soybean Genetic Modification* www.youtube.com/watch?v=wTraZwHDHXk, *Restriction Endonucleases (enzymes)* https://www.youtube.com/watch?v=GJrAsW41a64, and *3D Animation – Bacterial Transformation 3D Animation* https://vimeo.com/170630548

1. What is bacterial transformation? ____

2. Can bacteria transform naturally? If so, how? ____

3. What are plasmids? ____

4. What is the role of plasmids in bacterial transformation? ____

5. What is the role of DNA ligase? ____

6. Explain how the calcium chloride bath is used to insert the foreign DNA into the bacterial cell. ____

7. What happens when DNA is transcribed and replicated? ____

8. What do the scientists do to confirm that transformation has taken place? ____

Obtaining the desired gene

Scientists use one of several methods to screen and isolate the cell with the library plasmid containing the desired gene.

Isolation of the bacteria with the desired gene

The bacteria are plated onto a selective medium. Only bacteria with the desired gene and the selection marker gene will survive. The bacteria serve as a ready supply of the desired gene for use by scientists.

Isolation of the desired gene

The library plasmids with the desired gene are placed in a test tube with a restriction enzyme. The enzyme cuts the DNA at specific sites and frees the desired gene from the library plasmid.

Separation of the desired gene

The transformation plasmid with the desired gene is separated from the bacterial cells and purified

Preparation of the transformation plasmid parts

The desired gene, a selection marker gene, and “empty” transformation plasmid are cut to make them compatible for ligation.

Transference of the desired gene

Scientists choose an appropriate insertion method to insert the desired gene into the plant cells they are studying.

Ligation of the transformation plasmid parts

The desired gene, selection marker gene, and the “empty” transformation plasmid are combined in a test tube with a DNA ligase to seal the sticky ends of the DNA molecules together. This new bacterial transformation plasmid has incorporated the desired gene and the selection marker gene.

Propagating the genetically engineered plants

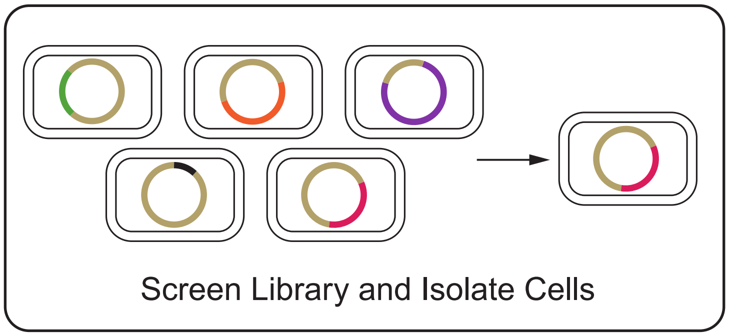
Plant cells are grown on selective media so that only the transformed cells carrying the new genes will grow. The media also contains substances that encourage the plant cells to grow into new plants.

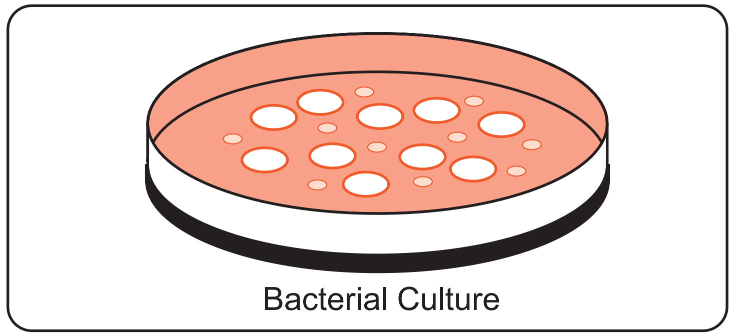
Addition of desired gene to bacteria

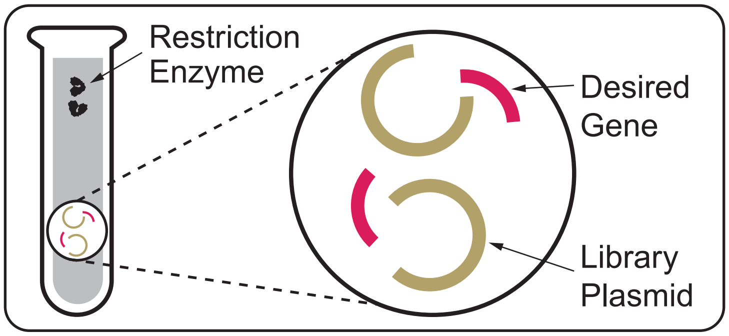
The transformation plasmid with the desired gene and the selection marker gene are added to bacterial cells.

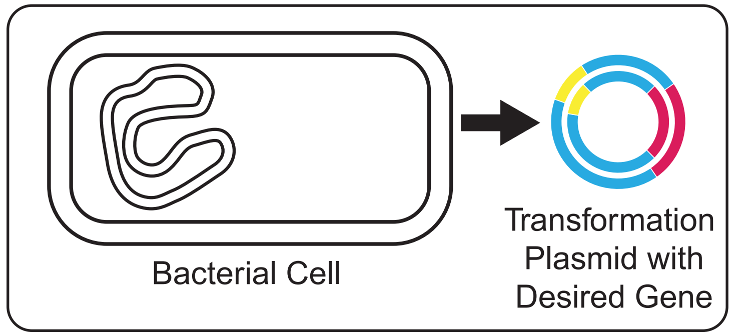
Testing the genetically engineered plants

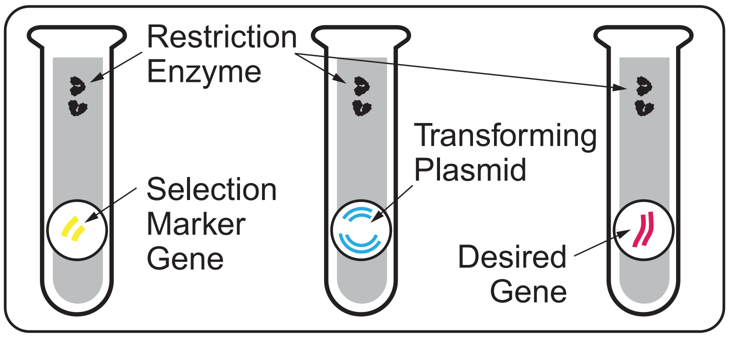
The plant is tested to determine if it incorporated the desired trait.

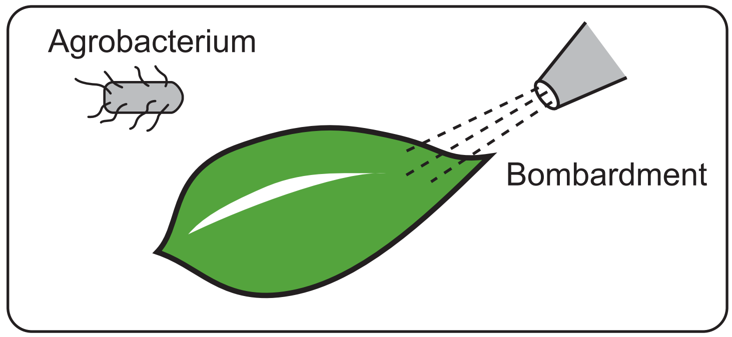

Screen Library and Isolate Cells

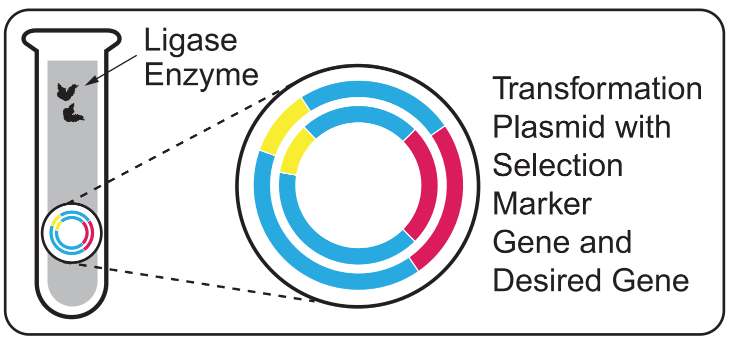

Bacterial Culture

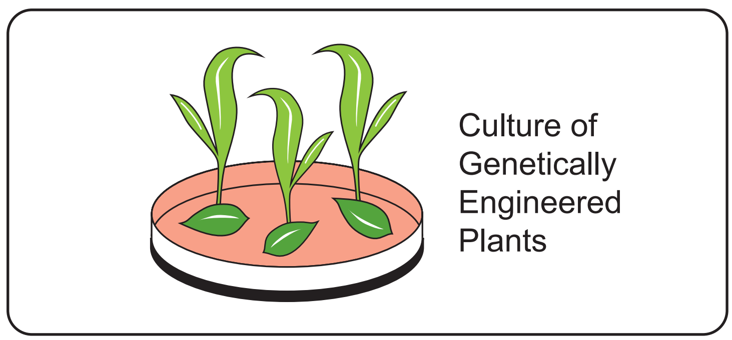

Restriction Enzyme
Desired Gene
Library Plasmid

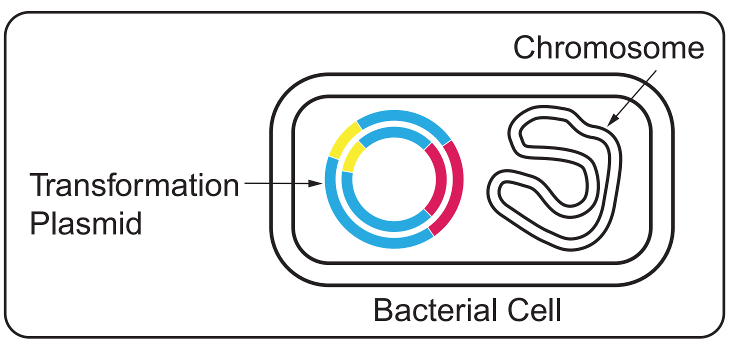

Bacterial Cell
Transformation Plasmid with Desired Gene

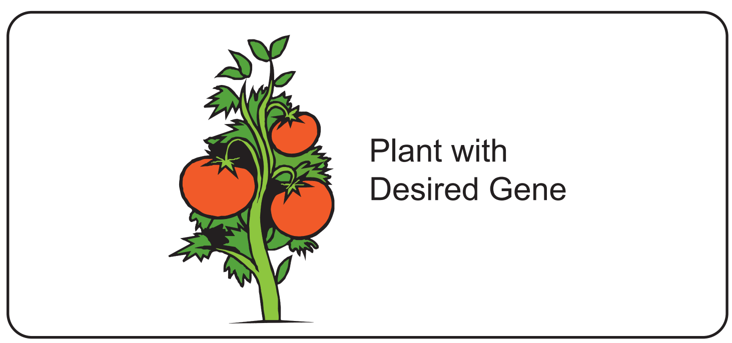

Restriction Enzyme
Selection Marker Gene
Transforming Plasmid
Desired Gene


Agrobacterium
Bombardment


Ligase Enzyme
Transformation Plasmid with Selection Marker Gene and Desired Gene


Culture of Genetically Engineered Plants


Chromosome
Transformation Plasmid
Bacterial Cell


Plant with Desired Gene

BACKGROUND INFORMATION

PART 2

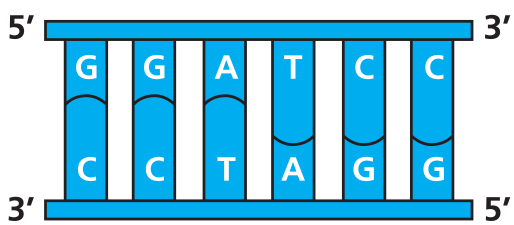
Targeted Genome Editing

While original rDNA techniques would often result in random integration of the desired gene(s), newer **genome editing** techniques use tools to target the desired gene or the "edit" to a precise locus in the genome. One genome editing technique currently used by plant scientists is the CRISPR-Cas system. It's part of a natural bacterial defense system that scientists are using to cut and modify DNA more precisely than any previous GE method.

What is CRISPR and how is it used by bacteria?

CRISPR stands for **Clustered Regularly Interspaced Short Palindromic Repeats**. CRISPRs are sequences of nucleotides in the bacterial genome where bacteria keep a record of previous infections by a virus and later use it to identify and fight subsequent attacks by the same virus. When a bacterial cell is infected by a virus, the cell incorporates pieces of the viral DNA into the CRISPR sequence, which then produces small, non-coding RNAs that act like virus detectors. This is a form of **adaptive immunity**.

Sample Palindromic Sequence



The sequence read in one direction on one strand matches the sequence read in the opposite direction on the complementary strand.

Acronym Alert

Early genetic engineering (GE) began about half a century ago, while genome editing is a more recent technique. Although both two-word phrases begin with a G and an E, in this curriculum, genome editing will always be spelled out, and GE refers to the broader category of genetic engineering techniques.

Close to the CRISPRs are **CRISPR-associated (Cas)** genes that encode for Cas proteins. In bacteria, Cas proteins are part of the adaptive immune system. Some Cas proteins help the bacterial cell to capture small pieces of invading viral DNA for insertion into the CRISPR sequences during the initial infection; others silence the attacking virus' DNA during subsequent infections to protect the bacteria. For example, the small RNAs made from the CRISPR sequence containing the previously captured pieces of viral DNA (from the first infection) bind to the Cas9 endonuclease enzyme and target it to cut the viral DNA of repeat invaders.

Developing CRISPR-Cas as a New GE Tool

In 2012-2013, several scientific teams tested whether they could adapt the bacterial CRISPR-Cas immune system for use as a genome editing tool. First, they determined which specific components of the system were needed: The Cas9 enzyme and a guiding RNA. Next, they showed that they could target the Cas9 enzyme to cut a specific locus of their choosing simply by changing part of the guiding RNA sequence to match the targeted genome sequence. Collectively, multiple scientific teams showed CRISPR-Cas9 could be used as a programmable RNA-guided DNA cutting tool in bacteria, plant, mouse, and human cells.

This discovery was important because it meant that scientists could now cut and "edit" genomic DNA at a specific location of their choice. When the cell tries to repair the broken DNA strand by joining the pieces back together, scientists could take advantage of this process to add or remove specific DNA sequences. They could also include a repair template (with a mutation or a new gene entirely) to guide a specific repair by the cell's own mechanisms. In agriculture, genome editing using CRISPR-Cas, or one of several other available DNA targeting and cutting tools, can be used to create plants that produce higher yields, are more nutritious, and have characteristics that will help them endure extreme weather conditions.

BACKGROUND INFORMATION

Here's the CRISPR-Cas9 process:

1. The scientist first identifies the precise location for the desired edit in the plant's genome.
2. A small piece of guide RNA is designed to target the DNA sequence at that location.
3. The guide RNA and Cas9 can be introduced into the plant cell as either DNA, RNA, or an RNA-protein complex called a ribonucleoprotein.
4. The guide RNA locates and binds to the targeted plant genomic DNA sequence. Its associated Cas9 enzyme then cuts the DNA at the targeted location.
5. The plant cell's own repair machinery re-attaches the cut DNA ends. During the process, nucleotides may be removed from or added onto the cut DNA ends. This can result in the loss of an undesirable trait or the expression of a new desired trait.
6. The cells are grown into mature plants with edited DNA.
7. The edited DNA is now heritable and can be passed on to the offspring.

Note: Depending on the method by which the guide RNA and Cas9 were introduced, they may not be present in the mature plant.

If the scientist includes a repair template during the plant transformation process (step 3), the repair template will direct the repair of the genomic DNA at the cut site (step 5).

CRISPR-Cas Delivery

There are several possible CRISPR-Cas delivery methods. Plasmid-mediated delivery transforms the cell with a plasmid or plasmids carrying the genes for the guide RNA and Cas protein, similar to rDNA technology. Alternatively, direct delivery of the Cas9 protein with guide RNA into plant cells can be used. The choice of delivery method depends on several factors, including which method is most efficient for the type of plant being edited and whether the scientist's goal is transient or stable expression of the CRISPR-Cas components.

In 2013, scientists discovered how to use the CRISPR-Cas system to edit a plant's genome. Since this discovery, many scientists throughout the world have been working to improve our food supply through genome editing using CRISPR-Cas as well as other targeted DNA cutting systems like TALEN and Zinc Finger Nucleases. These genome editing tools are being used to improve:

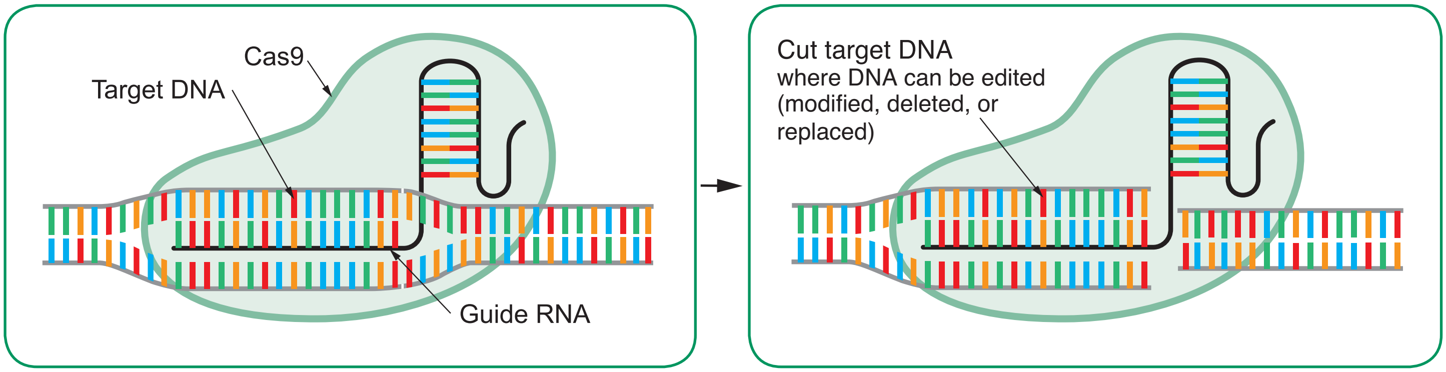
- a plant's yield performance
- nutritional value
- tolerance to biotic stress such as viral, fungal, and bacterial diseases
- tolerance to abiotic stress such as environmental conditions, including changes in water availability, temperature, and soil chemistry

The most studied crops are rice, corn, tomato, potato, barley, and wheat. Specific examples of researchers and their projects include scientists at Pennsylvania State University who used genome editing to extend the shelf-life of white mushrooms by disabling an enzyme that causes the mushrooms to brown, and scientists in Spain who used genome editing to modify the genome of wheat strains to be significantly lower in gluten.

The first food produced from a genome-edited crop became commercially available in 2019: High oleic soybean oil is lower in unhealthy fats than original soybean oil. Scientists are continually testing the potential of genome editing techniques to solve a range of food-related problems, such as:

- producing bananas that are resistant to a fungal disease that destroys the crop
- providing a solution to the citrus greening disease that is threatening U.S. orange trees
- protecting the world's chocolate supply by improving the cacao plant's ability to fight a virus that is destroying the crop in West Africa

CRISPR-Cas9



ACTIVITY 2 - TARGETED GENOME EDITING

TIME Three 45-Minute Class Periods

ACTIVITY AT A GLANCE

In this activity, students develop an understanding of the CRISPR-Cas9 gene editing system and create an infographic (or poster or model) to demonstrate their understanding of the system.

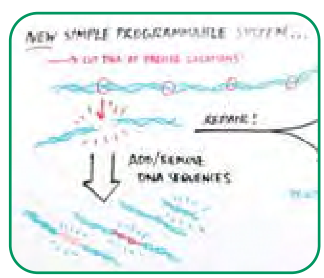
TIME TO TUNE IN

Gene Editing Yields Tomatoes That Flower and Ripen Weeks Earlier (2:50)
www.youtube.com/watch?v=Jem3hP734uA

CRISPR Gene Editing Explained (2:11)
https://video.wired.com/watch/crispr-gene-editing-explained

CRISPR Explained (Mayo Clinic) (1:38)
www.youtube.com/watch?v=UKbrwPL3wXE

CRISPR – A Word Processor for Editing the Genome (6:09)
www.ibiology.org/genetics-and-gene-regulation/crispr



TARGETED GENOME EDITING

GETTING STARTED

MATERIALS

- Computer and internet access for you and your students
- Copies of the **CRISPR-Cas Note-Taking Guide and Infographic** worksheet and the **Poster/Infographic Rubric** (page 94) for each student.
- Poster paper
- Markers
- 3 x 5 index cards
- Optional: 3D Modeling supplies

ADVANCE PREPARATION

Divide the class into small groups.

Make copies of the **CRISPR-Cas Note-Taking Guide and Infographic** worksheet and the **Poster/Infographic Rubric** for each student.

While the article, "Why Gene Editing is the Next Food Revolution," has some good information, point out to the students that it states that soybean-based oil is high in *trans* fats. However, this depends on whether the oil has been partially hydrogenated. If so, then the food companies may be required to remove the *trans* fats. This resource also states that genome editing techniques that mimic natural processes are not subject to U.S. regulation. However, regulatory debates are ongoing in the United States.

INTRODUCTION

Ask your class these questions:

1. ***How are scientists using genetic engineering to improve the food that we eat?***

   Possible answer: The genes from one organism can be added to the same kind of organism or to another kind of organism to make the plants more nutritious or resistant to disease.

2. ***Imagine that scientists can edit DNA as easily as correcting typos on a computer. What impact do you think this would have on the food that we eat?***

   The students might answer that it will be easier to change a plant's genes with targeted genome editing methods (such as the CRISPR-Cas system) than with non-targeted modification methods such as selective breeding, chemical or UV methods, and rDNA methods.

3. ***What advancements could you expect to see in agriculture in the next 5 years?***

   Some responses could include:

   1. There could be many more changes in the plants we eat.
   2. There could be more varieties of plants that we eat.
   3. Plants could become more nutritious or more resistant to pests.
   4. Our environment might be better because plants could be changed to reduce the need for certain pesticides.

   Tell the students that they will read text and view a video about the CRISPR-Cas9 system and then create an Infographic to illustrate their understanding of the system. Students could also consider creating a poster or powerpoint presentation.

TARGETED GENOME EDITING

STUDENT PROCEDURE

1. Read the questions on the **CRISPR-Cas Note-Taking Guide**, then watch these four videos:
   - *Gene Editing Yields Tomatoes That Flower and Ripen Weeks Earlier* www.youtube.com/watch?v=Jem3hP734uA
   - *CRISPR Gene Editing Explained* https://video.wired.com/watch/crispr-gene-editing-explained
   - *CRISPR Explained (Mayo Clinic)* www.youtube.com/watch?v=UKbrwPL3wXE
   - *CRISPR – a Word Processor for Editing the Genome* www.ibiology.org/genetics-and-gene-regulation/crispr
2. After viewing the videos, read the article: "Why Gene Editing Is the Next Food Revolution" - **https://www.nationalgeographic.com/environment/future-of-food/food-technology-gene-editing/** and then begin work on the Guide. Read carefully and take notes because you will use the information to create an Infographic or other visual presentation.
3. After completing the questions, discuss everyone's responses.
4. Discuss ways of visually representing knowledge designed to make complex ideas and large amounts of data easy to understand.
5. Consider how you will create your own infographic to help others better understand the CRISPR-Cas genome editing system.
6. Refer to A Visual Guide to Genetic Modification **https://blogs.scientificamerican.com/sa-visual/a-visual-guide-to-genetic-modification/**
   Look at the Conventional Crossbreeding Infographic to see what information can be learned from the infographic.
7. Answer the Infographic Planning questions listed at the bottom of page 40.
8. Consider the infographic examples at "Good to Better – A 'critique' with ideas & tips to improve your infographics" - **www.slideshare.net/hurricanemaine/infographic-good-and-better**. The slides have some good suggestions for improving infographics.
9. Now create a CRISPR-Cas infographic that explains how the system can edit the genome of a plant. Refer to the infographic "Second-Generation Gene Editing" or "What Is CRISPR" from "Why Gene Editing Is the Next Food Revolution" as models. Use other resources and include citations for each.

   Critical points for infographic project groups:
   - What information is essential? What isn't? (use your worksheet)
   - What colors and layout work best?
   - What is the best way to have the information flow?
   - Create a rough sketch of your infographic.
   - Determine how much copy (text) will be needed.
   - Balance copy with visuals.

   Infographics can be created digitally using a program such as Easel.ly - **www.easel.ly** or Piktochart - **https://piktochart.com**, or they can be made with poster paper and markers. Refer to the rubric criteria for your infographic.
10. Display the completed infographics in the classroom. Create a gallery walk and, using post-its®, discuss the best features of each infographic.
11. After the gallery walk, review the comments and using the rubric, score the infographics.

REVIEW

Ask the students for their anonymous review/evaluation of this activity on an index card using a 3-2-1 evaluation:

- List 3 things they have learned
- List 2 questions they still have
- List 1 concern

Students can refer to the resources they have used in this activity. Review their answers and discuss them with the class the next day.

TARGETED GENOME EDITING

EXTENSIONS

Students could do one or more of the following activities:

1. Review the video *CRISPR Gene Editing Explained*, which uses the analogy of a toy train to explain the CRISPR-Cas system, and design an infographic that uses a similar analogy to explain the system. **https://video.wired.com/watch/crispr-gene-editing-explained**
2. View the video *CRISPR – History of Discovery* **www.youtube.com/watch?v=RKh2mi3tsmc** and create an infographic about the history of the development of the CRISPR-Cas9 system.
3. Research multiple genome editing techniques, such as CRISPR-Cas, TALEN, and Zinc Finger Nucleases, and compare and contrast their characteristics and advantages in a chart.

SUMMARY

Genome editing techniques like CRISPR-Cas are powerful tools that scientists can use to target specific locations in the genome for editing (add, remove, or modify a gene to increase or decrease its expression) and thus change the traits of that organism. The promise and challenges that genome editing systems hold for agriculture are currently unknown. But, based on the results we have now, it is exciting to think about crops of the future and what they might be able to do.

UP NEXT

Now that you know about some of the tools farmers and scientists have to select or alter plant traits, let's take a look at some of the environmental factors that can challenge or help plants grow in the field.

RESOURCES

- *A Visual Guide to Genetic Modification*
  https://blogs.scientificamerican.com/sa-visual/a-visual-guide-to-genetic-modification/
- *CRISPR – A History of Discovery*
  www.youtube.com/watch?v=RKh2mi3tsmc
- *HHMI Biointeractive: CRISPR-Cas9 Mechanisms & Applications*
  media.hhmi.org/biointeractive/click/CRISPR/
- *Nature Video: CRISPR Gene Editing and Beyond*
  www.youtube.com/watch?v=4YKFw2KZA5o
- Science Magazine (more technical option)
  CRISPR-Cas guides the future of genetic engineering
  http://science.sciencemag.org/content/361/6405/866
- *New Gene Editing Tool May Yield Bigger Harvests*
  www.youtube.com/watch?v=UUo6IxLRbQ4
- *What is CRISPR-Cas?*
  www.youtube.com/watch?v=52jOEPzhpzc
- *Future Predictions – Food Technology and Science*
  www.youtube.com/watch?v=GCXhdAGx3NI

CRISPR-CAS NOTE-TAKING GUIDE AND INFOGRAPHIC WORKSHEET

Name ______________________________ Date ____________ Class/Hour __________

Directions: Watch the following four (short) videos and read the article about gene editing; then answer the questions.

- *Gene Editing Yields Tomatoes That Flower and Ripen Weeks Earlier* www.youtube.com/watch?v=Jem3hP734uA
- *CRISPR Gene Editing Explained* https://video.wired.com/watch/crispr-gene-editing-explained
- *CRISPR Explained (Mayo Clinic)* www.youtube.com/watch?v=UKbrwPL3wXE
- *CRISPR – a Word Processor for Editing the Genome* www.ibiology.org/genetics-and-gene-regulation/crispr

Why Gene Editing Is the Next Food Revolution - www.nationalgeographic.com/environment/future-of-food/food-technology-gene-editing, complete the following questions.

1. Why do scientists want to be able to edit DNA? ______________________________
2. What is CRISPR and how do scientists use it? ______________________________
3. In what type of organism was CRISPR first discovered? ______________________________
4. What does the acronym CRISPR stand for? ______________________________
5. What is Cas? ______________________________
6. How did scientists harness or program the CRISPR-Cas9 system they identified in bacteria? ______________________________
7. Describe the steps in the CRISPR-Cas system. ______________________________
8. List some potential benefits/applications of CRISPR technology for our food. ______________________________

Infographic Planning

Remember: An infographic: (1) Is an explanation that helps you more easily understand something, (2) integrates words and pictures, (3) is self-explanatory, (4) makes for faster understanding of a concept, and (5) is understandable.

1. Review "A Visual Guide to Genetic Modification" https://blogs.scientificamerican.com/sa-visual/a-visual-guide-to-genetic-modification
2. After reviewing the first infographic "Conventional Crossbreeding," consider the following questions:

   What makes this infographic interesting – the content, the design, or both?

   How was the information arranged and presented? Were there sections, titles, and/or graphs?

   How are fonts, color, and graphics used?

   Did the design contribute to how you felt about the information?

   What did you like about the infographic?

   What would you change in the infographic to make it better?
3. As you design your infographic, consider the following questions:

   What is your goal?

   Who is your audience?

   What information do you want to include?

   What information is essential? What information is not?

   Did you create an outline to organize your information?

   How will you arrange your flow of information?

   What colors and layout work best?

   Have you streamlined your information?
4. Use the back of this page or another sheet of paper to design a rough sketch of your infographic.

MODULE 3 ENVIRONMENTAL FACTORS

This module introduces environmental factors (focusing on pests) that can challenge crop growth, discusses a range of GE and non-GE strategies farmers might use to optimize their crop conditions, and includes engaging activities for students to learn about managing these environmental challenges.

For this module, it is recommended that teachers will have already taught students the following underlying key concepts: Biotic versus abiotic environmental factors, how food chains and food webs model the flow of energy through ecosystems, point source pollution, natural resource definition, renewable versus non-renewable natural resources, natural resource conservation (i.e., reducing, reusing, and recycling), pathogens, and introductory concepts in genetic engineering.

BACKGROUND INFORMATION: PART 1

Growing Food Challenge introduces students to key environmental factors, e.g., pests, that impact crop success.

Time to Tune In
This overview video identifies multiple agricultural practices and how they relate to the environment for students who are less familiar with these topics.
Agriculture - Environmental Science (Bozeman Science) (9:24)
www.youtube.com/watch?v=OGf04jPEaT0

ACTIVITY 1

Agricultural Pests enables students to identify and define crop pests.

Time to Tune In
The Amazing Ways Plants Defend Themselves (6:12)
https://ed.ted.com/lessons/the-amazing-ways-plants-defend-themselves-valentin-hammoudi

Do We Really Need Pesticides? (5:18)
www.youtube.com/watch?v=GLIlZ-qiXJA

ACTIVITY 2

Pest Management Research Project introduces students to a variety of GE and non-GE pest management strategies that a farmer might use.

Time to Tune In
G.A.P in Action: Integrated Pest Management (2:46)
www.youtube.com/watch?v=7qQCLMFjRew

BACKGROUND INFORMATION: PART 2

What Is Citrus Greening? is a case study in which students will learn about various pest management approaches to protect citrus crops from this disease.

ACTIVITY 3

Citrus Greening Disease Management engages students to consider potential citrus greening management strategies. **Advanced Activity**

Time to Tune In
Bitter Fruit - Citrus Greening Disease Threatens Florida Industry (2:52)
www.youtube.com/watch?v=T5nqVmliUaM

BACKGROUND INFORMATION

PART 1
Growing Food Challenge

Plants growing in a natural environment face several challenges that affect which plants will survive and grow, produce seed, and complete their life cycle. Various pests such as weeds, herbivores, and pathogens can threaten plant production of grain, fruit, or flowers. Cultivated plants can have other stressors such as dry weather or a lack of soil nutrients. As a result, growers often manage their fields to reduce stress through methods such as irrigation, fertilization, and pest control to increase crop production.

Crops and their environment have an impact on one another. In agriculture, various approaches impact water use, pesticide use, and CO_2 release (**carbon footprint**). Tillage practices, fertilizer use, conventional pesticides, biopesticides, etc., are all factors that impact a crop's environmental footprint. **Environmental footprint** is the effect that a person, company, activity, etc., has on the environment, e.g., the amount of natural resources that a crop uses and the amount of harmful gases it produces.

Official Definition of Pest – An organism is declared to be a pest under circumstances that make it deleterious to man or the environment, if it is: (a) Any vertebrate animal other than man; (b) Any invertebrate animal, including but not limited to, any insect, other arthropod, nematode, or mollusk such as a slug and snail, but excluding any internal parasite of living man or other living animals; (c) Any plant growing where not wanted, including any moss, alga, liverwort, or other plant of any higher order, and any plant part such as a root; or (d) Any fungus, bacterium, virus, prion, or other microorganism, except for those on or in living man or other living animals and those on or in processed food or processed animal feed, beverages, drugs, and cosmetics. (U.S. Code of Federal Regulations)

Approaches to pest control include mechanical, biological, chemical, or cultural techniques. Some growers also use **Integrated pest management (IPM)**, a decision-making framework that helps growers decide when to apply pest control and which control techniques to use. IPM focuses on long-term pest control and aims to minimize pest impact on crop quality.

Methods of Pest Control in Crops

Method	Examples
Mechanical	Tilling, Mulching
Biological	Biological pesticide, Beneficial insects, Disease-resistant plant varieties developed through conventional breeding or GE methods
Chemical	Pesticides, Insecticides, Herbicides, Fungicides, Nematacides, Rodenticides, Bactericides
Cultural	Irrigation, Crop rotation, Mixed cropping, Cover cropping, Row covers, Sanitation

MECHANICAL PEST CONTROL

Plant pests can be controlled in many ways. Simply pulling weeds from a garden or flower bed reduces the competition for moisture and plant nutrients and helps avoid the insects those weeds might attract and harbor. This is known as a physical or mechanical control method of plant protection. Plant pest control often starts with preparing a site to make it harder for pests to survive. For example, a grower might **till** (turn over) the soil or put down mulch cloth to reduce weeds. Reduced tillage systems are also common and have certain benefits, such as reduced soil erosion.

Farmers can use different tilling methods to prepare soil before planting. **Reduced tillage** includes different approaches that conserve soil by leaving more plant residue on the soil surface and uses less energy. **No-till** is a method that leaves the soil undisturbed through use of a coulter (a vertical blade) that slices the soil, and another tool that places the seed at a proper depth. However, even in no-till systems, farmers may need to till every few years to reduce crop debris that could harbor crop pests such as insects and pathogens. **Conventional tillage** normally involves three or more steps using tractor-pulled tools. The environmental footprint varies with different tillage methods of pre-planting soil preparation.

BACKGROUND INFORMATION

BIOLOGICAL CONTROLS

Biological controls are more complex than simply plowing a field. They use a biological organism or process to protect plants from damage caused by other organisms. Several types of natural or biological plant protection innovations have been developed throughout farming history. The most commonly used are:

1. Selective breeding to cultivate damage-resistant plants
2. Use of beneficial organisms to control weeds or insect populations
3. Biopesticides produced from microbial cultures, plants, or other organisms
4. GE plants designed to resist pests

Biological Control Using Predators

Biological control with predators uses an organism (such as an herbivore, predator, pathogen, or parasitoid) that consumes the pest to reduce pest populations. For example, predator insects such as lady beetles and lacewings eat other insects. Parasitoid insects such as wasps lay their eggs on or in some life stage of the target insect. After an egg hatches, the developing immature stage of the parasitoid insect kills the targeted host by consuming the host tissues. Biological control might also involve releasing beneficial organisms to the environment or changing the landscape to increase populations of beneficial organisms.

Limitations of Biological Control Using Predators

There are limits to the safety and effectiveness of biological insect control. For example, it may be necessary to eliminate or reduce the use of broad-spectrum pesticides, since both beneficial and target insects could be killed. Fungicides used against plant pathogenic fungi can also impact desired fungi when applied to reduce insect pests. In addition, strict regulations must be used to ensure that today's insect predator will not become tomorrow's pests.

Managing an insect attack can be complicated, because the attacking predatory or parasitoid insects cannot thrive until there are sufficient numbers of target insects to serve as prey or hosts. Some biocontrol insects may also destroy a broad range of insects – both beneficial and harmful. Sometimes beneficial insects can be considered pests when they become too numerous or are in the wrong place. Invasive lady beetles from Asia have displaced some native species in the United States. They can also become minor pests in the home when they invade in large numbers when weather starts to turn cool.

CHEMICAL CONTROLS

Pesticide use is one of many management practices in agriculture. Continuous pressure to feed increasing populations has influenced agriculture to progress through many stages from domestication and improvement of crop plants, to mechanization, fertilization, and pesticide use. Pesticides are applied to crops, gardens, animals, lawns, recreational areas, and around homes and other buildings. They help provide abundant, disease-free, pest-free foods, improve crop yield, and reduce disease vectors for humans, animals, and plants.

Pesticides were considered necessary in crop production in the mid-twentieth century and were often applied in multiple passes across the field. Pesticides still are considered necessary in crop production, but improved technology provides pesticide options that are more compatible with other control methods and reduce environmental consequences. In addition, more judicious pesticide application has evolved over time, with application following field scouting to ensure that pesticides are only applied when there is a danger that pests may reach levels that significantly impact a crop's sale value.

DID YOU KNOW?

Many plants have evolved to produce natural compounds to defend themselves from pests. Some of these substances are potentially harmful to animals (including humans) that eat the plants. How harmful a consumed substance is for humans or animals varies depending on exactly what the substance is and how much is consumed (the dose).

There are different types of pesticides such as herbicides, fungicides, insecticides, rodenticides, etc. Different herbicides are designed to be most effective at different timings: Some are only applied before planting to control germinating weed seeds, and others are applied after the crop plants emerge.

Pesticides are often used to solve plant pest problems, but if they are used incorrectly, some of them might not provide the desired results or can harm crop plants or the environment (including groundwater, lakes, or rivers). Pesticides are evaluated for their impact on the environment and for how they may affect the health of people who may be exposed to the pesticides. The U.S. Environmental Protection Agency (EPA) works with the U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) to monitor use of chemicals in food production and determine levels of safe use.

Pesticide Impact on Humans

Pesticides may contain chemicals with possible health risks to humans. The risk is determined by the hazard and exposure,

BACKGROUND INFORMATION

i.e., how someone comes into contact with the pesticide (ingested, inhaled, or through skin contact).

The EPA classifies pesticides based on their chemical toxicity and separates them into four categories – Category I, II, III, or IV, with Category I chemicals being the most toxic. Using these categories, EPA restricts where the pesticide can be applied, how much can be applied, and also anticipates its possible exposure level to humans.

Pesticide Impact on the Environment

Some pesticides can contaminate soil, water, turf, and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to other organisms including birds, fish, beneficial insects, and non-target plants.

For the last 30 to 40 years, researchers have been developing pesticides that are more specific to their target pests and that have a reduced impact on the environment. Different pesticides also break down at different rates, which are further influenced by conditions such as moisture and temperature.

A **Risk Quotient (RQ)** is used to quantify the environmental impact of most commonly used pesticides (insecticides, fungicides, and herbicides) in agriculture and horticulture. The RQ value is calculated using key factors such as a pesticide's active ingredient(s), toxicity, amount applied, and how long it persists in the environment. RQ values allow pesticide options to be compared.

Biological Pesticides (Biopesticides)

The most widely applied bacterial species used as a biological pesticide is *Bacillus thuringiensis* (*Bt*), a bacterium found in soil. *Bt* produces a natural crystal protein that is toxic to some other organisms like insects and nematodes. Some strains of the *Bt* bacterium produce toxins that are naturally highly specific to certain pest insects, but harmless to most other organisms. When *Bt* produces spores, a toxic crystal protein is formed inside the spore. The spores are suspended in a liquid and sprayed on the plants. When a targeted pest eats the spores, the crystal toxin is released, and the pest will die. *Bt* spores are regarded as safe to humans and the environment because they are so specific to a few types of insects.

There are many other natural organisms that can be used to produce a biological pesticide. Researchers in Florida are growing a naturally occurring fungus, *Hirsutella citriformis,* to fight the Asian citrus psyllid (jumping plant lice). Asian citrus psyllids are small insects that feed on citrus plants. They can transmit the bacteria that causes citrus greening disease to their host plants.

Citrus greening is one of the most serious citrus plant diseases in the world and affects many citrus trees in Florida and the South. It is also known as Huanglongbing (HLB) or yellow dragon disease. An infectious virus of citrus known as Citrus tristeza virus (CTV) is being evaluated as a vector of biologically active peptides targeting the HLB bacterium into the cells of the citrus trees. While CTV is a pathogen of citrus, it can be used as a biological control of HLB in this case, because it uses CTV strains that have been selected to cause only a few mild symptoms when trees are infected.

Tillage methods influence pest control. In conventional tillage, few selective herbicides may be needed because the tillage helps to control weeds. Reduced tillage and no-till systems may require broad-spectrum (less selective) herbicides because there is less tillage. However, reduced tillage and no-till systems may have benefits such as enhanced nutrient cycling and water retention. Conventional tillage releases the most greenhouse gas when stored carbon in the soil is released into the atmosphere and more fuel is used for power tilling equipment.

DID YOU KNOW?

Some people think all food that is labeled "organic" was grown without pesticides. However, there are many "organic" pesticides approved for use in growing food crops that can be labeled "organic." *Bt is* an organic pesticide. For a complete list of allowed and prohibited substances, see USDA's National Organic Program list: **www.ams.usda.gov/about-ams/programs-offices/national-organic-program**

FOCUS ON GE PLANTS

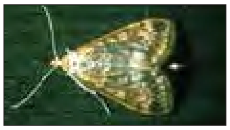
GE Plants with Enhanced Traits (Biotechnology)

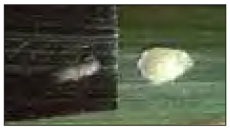
Several GE crops have been developed specifically to be **insect resistant (IR)** or **herbicide tolerant (HT)**. IR *Bt* GE crops have been designed to produce a protein that kills specific target insects, such as the European Corn Borer, when they attack the plant. These proteins only affect specific receptors in the gut of certain target pests and are harmless to humans, mammals, and most non-target insects.

One unanticipated consequence of this pesticide specificity is the resurgence of some secondary pests (e.g., cutworms, wireworms) that are not targeted by the *Bt* endotoxin and can become primary pests in some years, in some locales. HT crops are designed to tolerate specific broad spectrum (non-selective) herbicides, which kill surrounding weeds but leave the cultivated crop intact. Glyphosate-tolerant crops are the most prevalent, although many new combinations of HT mechanisms are also used with older herbicides, such as dicamba, that are used commercially. In addition, HT traits are not required for reduced tillage or no-till practices, but they can make it easier for farmers to use these practices.

BACKGROUND INFORMATION

European Corn Borer


adult female


eggs


pupa


larva


husk injury


stalk damage

Photo credit: Pennsylvania State University Entomology Department

Biotechnology Approaches to Combat Plant Diseases

According to CropLife International (an association that promotes agricultural technologies such as pesticides and plant technology), more than a third of the world's potential crop production is lost each year to pests and plant diseases. Most crops can be damaged by diseases caused by soil-borne plant pathogens and insect-vectored viruses. The three predominant types of plant disease agents are viruses, bacteria, and fungi.

- Combating viral diseases: Scientists have transferred virus genes, such as those that produce a virus coat protein, into plants. This acts like a vaccine that makes the plant resistant to that specific virus. Another way to increase plant resistance to viral infections is to inhibit the vectors, such as insects and nematodes, that carry the virus.
- Combating bacterial diseases: All crop plants are susceptible to bacterial infections. Bactericides, including antibiotics, are not a complete solution, because bacteria quickly evolve resistance to them, and this could have implications for treatment of infections in man and animals.

  Fire blight is an example of a harmful bacterial disease that destroys pears, apples, quince, and some ornamental plants. One remedy is to spray trees with large quantities of antibiotics. Scientists have identified DNA markers for fire blight resistance and are working to develop resistant varieties.
- Combating fungal diseases: Fungi cause billions of dollars in crop losses each year. They attack nearly all fruit, vegetable, and grain varieties. Some plants are more susceptible to fungal diseases than others, simply because they are too slow to start fighting back after they are attacked, or they lack the resistance gene for that particular fungus. Some techniques can trigger these plants to respond sooner by treating them with fungal pathogens that have been disarmed, or by using resistance inducers like salicylic acid, a naturally occurring plant biochemical, making the fungus harmless to the plant.

DID YOU KNOW?

Viroids, algae, and parasitic plants can also be disease agents or pests of crops. Viroids are similar to viruses but without the coat protein and with their own unique properties; they are folded RNA molecules with secondary structure and can cause significant diseases, e.g., potato scab.

Environmental Impact of Growing GE Plants

GE crop technology has been used widely since the mid-1990s in several countries and has mainly been used in four main crops: canola, maize, cotton and soybean. The adoption of GE IR and HT technology has significantly reduced certain insecticide and herbicide use. Source: www.ncbi.nlm.nih.gov/pmc/articles/PMC6277064/

Generally, less fuel is consumed in the production of major GE crops because the HT traits make no-till practices easier to use, which results in lower carbon dioxide emissions. Specifically, HT GE crops require less tilling. The no-till process requires effective herbicide control of weeds in lieu of mechanical tillage and is facilitated by the adoption of HT crops. Farmers use less fuel because fewer passes are made through the field to till and to spray herbicides on GE crops.

The no-till method also reduces erosion on susceptible land in steep terrain or fragile landforms and reduces chemical use. The use of plants modified to resist corn borer and rootworm has also decreased insecticide use. These production practices allow GE crops to have increased yield, which also makes food cheaper to produce on less land.

GE crops are sometimes blamed for lowering genetic diversity of crops and speeding the development of herbicide resistance in weeds. However, when farmers use seeds from fewer family lines, diversity decreases regardless of whether GE or non-GE seeds are used. In addition, herbicide use can result in the selection of weeds resistant to the herbicide in GE or non-GE crops. Herbicide-resistant weeds have long been a concern for farmers. The availability of HT GE crops has arguably resulted in faster selection of weeds resistant to the herbicide, but GE crops with multiple HT features could also help slow the selection of herbicide-resistant weeds.

How serious is weed resistance to pesticides?
In the United States, there are currently 14 weeds associated with common crop production that are resistant to the most popular non-selective, post-emergent herbicide. (International Survey of Weed Resistance www.weedscience.org)

ACTIVITY 1: AGRICULTURAL PESTS

TIME Two 45-Minute Class Periods

ACTIVITY AT A GLANCE

The crops we eat are constantly at risk of harm from pests. But what are these pests? In this activity, students will develop a definition of an agricultural pest that is meaningful to them and identify categories of pests such as insects, rodents, mollusks, weeds, and diseases.

TIME TO TUNE IN

The Amazing Ways Plants Defend Themselves (6:12)
https://ed.ted.com/lessons/the-amazing-ways-plants-defend-themselves-valentin-hammoudi

Do We Really Need Pesticides? (5:18)
www.youtube.com/watch?v=GLlIZ-qiXJA

Agriculture - Environmental Science (Bozeman Science) (9:24)
www.youtube.com/watch?v=OGf04jPEaT0

GETTING STARTED

MATERIALS

- Pictures of pests that affect our food crops. Pests should include insects, mites, weeds, and, if possible, diseases. See the Resource box (on page 49) for sources of downloadable pictures; consider citing local pests from your state/region.
- Pictures of beneficial organisms similar to the pests you chose – the resource list also contains sources for these pictures
- Internet access
- **Agricultural Pests** worksheet
- **Credible Source Guide**

ADVANCE PREPARATION

- Divide your class into small groups.
- Print and number a set of pictures for each group; alternatively, prepare a PowerPoint presentation of the pictures.
- Make copies of the **Agricultural Pests** worksheet and **Credible Source Guide** for each student.

AGRICULTURAL PESTS

INTRODUCTION

Agricultural Pests is the first of three activities in this module. In the second activity, students will research a specific agricultural pest and prepare a chart to display their research. In the third activity, students will learn about citrus greening disease and they will research different management programs for the disease.

Through discussion and observation of both agricultural pests and beneficial organisms, students will develop a working definition for "agricultural pest." Their final definition should be meaningful and could be similar to these:

- An **agricultural pest** is an organism living and growing where it is not wanted and can cause damage to the crops that are grown for food.
- It is an unwanted organism: A living thing that competes with people for food and fiber, attacks people or livestock directly, or annoys or otherwise affects aesthetic human values.

STUDENT PROCEDURE

1. Make sure that everyone in your group has their own copy of the **Agricultural Pests** worksheet.
2. You will need to create a definition of "agricultural pest." Brainstorm with your group about examples of organisms you think might be pests.
3. Take notes and make changes in your definition as you discuss options with your group.
4. Look through the set of agriculture-related pictures provided for each group.
5. Complete the data table as you review your pictures. Research the organisms online to learn if they are pests or beneficial and why they belong in this category. Use the **Credible Source Guide** as you do your research.
6. Select a "Fact Checker" for your group. Upon completion of the data tables, each group should present their findings, and a Fact Checker from another group should verify their accuracy.
7. Your teacher can provide names of a few organisms to research if you weren't able to fill your table.
8. When you have completed your data table, watch the two videos about agricultural pests. The first video shows how plants can defend themselves and which pests might affect the plants. As you watch each video, record the names of the different pests.

   The Amazing Way Plants Defend Themselves
   https://ed.ted.com/lessons/the-amazing-ways-plants-defend-themselves-valentin-hammoudi

   Do We Really Need Pesticides?
   https://ed.ted.com/lessons/do-we-really-need-pesticides-fernan-perez-galvez#review

   After you have viewed both videos, discuss the various pests shown in the video.

   If pictures of fungal and bacterial pests were not used at the beginning of this activity, look at some pictures of the effects of these organisms. Most of them are microscopic and cannot be directly observed—what we observe are the effects of the organism living in or on the plant.

   You might see information about *Candidatus* Liberibacter asiaticus *(CLas),* the bacterium that causes citrus greening disease, which is the subject of Activity 3 in this module. This bacterium currently cannot be cultured on Petri dishes the way many other plant pathogens can be cultivated.

AGRICULTURAL PESTS

REVIEW

Students should review their notes and create a final working definition of "agricultural pest". The definition should be similar to the one below, but it does not need to be exact and should have meaning to the students. This is the definition that your students should understand by the end of this activity:

An agricultural pest is an organism living and growing where it is not wanted and can cause damage to the crops that are grown for food.

SUMMARY

We rely on crops grown on farms to supply us with the food we need to sustain a healthy life. To ensure that these crops are grown successfully, farmers must manage the pests that feed on or harm the crops. There are several methods of pest control in farming; the use of pesticides is one method that farmers use to to control these pests. There is a wide variety of pesticides and each type targets a certain type of pest. Insecticides target insects; fungicides target fungi; and herbicides target weeds. In addition to pesticides, there are many other methods that farmers use to control pests.

EXTENSIONS

Students could do one or more of the following activities:

1. Pick their favorite fruit and/or vegetable and identify up to three pests that attack them and at least one insect that is beneficial to each fruit or vegetable.
2. Find pictures of labels from pesticide containers to identify the pests that are controlled by this product. What other information about the pesticide is provided on the label?
3. Make a list of pests that might be in and around your school and discuss their potential effects on the school environment.
4. Select crops that grow in your state and research several of the different pests that affect those crops.
5. Create a large Venn diagram with the headers: Pest, Beneficial, and Both. Students can write the names of organisms in the appropriate areas of the diagram.

AGRICULTURAL PESTS

RESOURCES

- *Hungry Pests – USDA*
  www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/?utm_campaign=crosby-2017&utm_source=hungrypests-com&utm_medium=redirect&utm_keyword=home
- *Plant Pests and Diseases Programs*
  www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases
- *Pest Tracker*
  www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/Pest-Tracker?utm_campaign=crosby-2017&utm_source=hungrypests-com&utm_medium=redirect&utm_keyword=/the-spread
- *Agricultural Pest Survey Cooperative – Pest Lists*
  http://caps.ceris.purdue.edu
- *History of Pesticides*
  www.youtube.com/watch?v=gyZPDcr5_dw
- *How Plants Make, Store, and Use Toxins*
  https://learn.genetics.utah.edu/content/herbivores/planttoxins/
- *Top Crop: Farming for the Future Educator's Guide*
  https://www.nationalgeographic.org/media/top-crop-farming-future-educators-guide/
- *Pesticide Labels*
  www.epa.gov/pesticide-labels
- *What is Integrated Pest Management (IPM)?*
  https://www2.ipm.ucanr.edu/What-is-IPM
- *University of Wisconsin - Agroforestry Practices: Strategies for Implementation*
  www.youtube.com/watch?v=PRm4jnxCeMw
- *Apple Fire Blight*
  www.youtube.com/watch?v=PdcDXNftoWg

Pictures of pests:

- *Agricultural Pests - UC IPM crop lists showing pests that affect each crop*
  http://ipm.ucanr.edu/PMG/crops-agriculture.html
- *Natural Enemies Gallery - UC IPM list of predators with pictures*
  http://ipm.ucanr.edu/PMG/NE/index.html
- *USDA Image Gallery* – pictures of many crop pests
  www.ars.usda.gov/oc/images/image-gallery (use search function)
- *Virginia Tech Weed Identification Guide*
  http://oak.ppws.vt.edu/~flessner/weedguide

UP NEXT

Now that you have identified some agricultural pests, let's look at some ways farmers try to manage them to protect their crops.

STUDENT WORKSHEET

ACTIVITY 1: AGRICULTURAL PESTS

Name ______________________________ Date ____________ Class/Hour __________

Write your working definition for agricultural pests here: ______________________________

____

____

DATA TABLE

Name and Kind of Organism	Pest or Beneficial	Action

List the pests that affect the plants shown in the video, *The Amazing Way Plants Defend Themselves*
https://ed.ted.com/lessons/the-amazing-ways-plants-defend-themselves-valentin-hammoudi

____

____

List the pests that affect agricultural crops shown in the video, *Do We Really Need Pesticides*?
https://ed.ted.com/lessons/do-we-really-need-pesticides-fernan-perez-galvez#review

____

____

Final working definition for agricultural pests: ______________________________

____

____

ACTIVITY 2: PEST MANAGEMENT RESEARCH PROJECT

TIME Three 45-Minute Class Periods

ACTIVITY AT A GLANCE

Students will become familiar with a specific agricultural pest, the damage it can cause to crops, and the variety of GE or non-GE programs that a farmer might use to manage that pest.

TIME TO TUNE IN

G.A.P in Action: Integrated Pest Management (2:46)
www.youtube.com/watch?v=7qQCLMFjRew

IPM in Agriculture (4:14)
www.youtube.com/watch?v=WTsXozqyGQU

Powdery Mildew: Identification and Management (4:18)
https://smallgrains.ces.ncsu.edu/smallgrains-powdery-mildew/

GETTING STARTED

MATERIALS

- List of agricultural pests to be researched such as vertebrates, mollusks, insects, mites, weeds, fungi, and bacteria
- Internet access
- **Pest Management Research Project** worksheet– one for each group
- **Poster/Infographic Rubric** – one for each group
- **Credible Source Guide** – one for each group
- Supplies to create posters
- Sticky notes in 3 different colors

ADVANCE PREPARATION

- Divide the class into small groups of 2 or 3 students.
- Create a list of agricultural pests from one of the lists in the Resource box (on page 54). Your list should include pests that would typically affect crops in your state and could be vertebrates, mollusks, insects, mites, weeds, fungi, and bacteria. Note: The insect, Asian citrus psyllid, and the bacterium, *Candidatus* Liberibacter asiaticus (CLas), associated with citrus greening disease, are the subject of Activity 3 in this module and should not be used in this activity.
- Each group should choose a pest from this list to research.
- If there are students who may be challenged by this research or if there are time constraints, direct them to USDA's Hungry Pests Website, which includes much of the needed information on one page. Hungry Pests – USDA - www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/?utm_campaign=crosby-2017&utm_source=hungrypests-com&utm_medium=redirect&utm_keyword=home
- Make a copy of the following materials for each group: **Pest Management Research Project** worksheet; **Poster/Infographic Rubric**; **Credible Source Guide**.
- Gather materials the students will need to create their posters.

PEST MANAGEMENT RESEARCH PROJECT

INTRODUCTION

Your students will research a specific pest and prepare a poster (or infographic) that should include background information about that pest, as well as information about the GE and non-GE programs that are used to manage the pest.

STUDENT PROCEDURE

1. Review your definition of agricultural pest from the previous activity. You will now research a particular agricultural pest and the programs that are used to manage that pest, and will create a poster that will be shared with other groups.

2. Select an agricultural pest for your group to research from the list provided by your teacher.

3. Review the information that should be included on the poster:
   - Identification and proper description of the pest, and inclusion of a picture/drawing
   - Identification of the specific crops affected and to what extent each crop is affected
   - Explanation of which part of the pest's life cycle is most destructive
   - Explanation of how the pest causes damage to the crops
   - Identification of the pest as native or non-native to the United States and, if not, how it came to the United States
   - How much of the pest must be present for it to significantly harm the crop
   - Current methods (GE and non-GE) used to manage the pest, including if they are biological, cultural, mechanical, chemical, or a combination of methods. Include which management method, if any, is most effective, whether the management method controls or exterminates the pest population, and financial cost (if available)
   - Any other significant environmental effects of each management method
   - What the consequences would be for the crop if the pest is not managed
   - Summary/conclusion: Which method(s) is/are optimal and provide(s) the greatest pest control with the least collateral harm
   - Recommendation for a new or different method of pest control, if possible

4. Watch the three videos listed in the **Time to Tune In** section (page 51) at the start of this activity. They introduce different agricultural pests and pest management approaches.

5. When all of the groups have completed their posters and displayed them around the room, conduct a gallery walk for peer review and feedback. One group member should stay with each poster to explain their research and answer questions while the other group members review the other posters.

   Use three different colored sticky notes to write your feedback:
   - record one thing you liked about each poster
   - one thing you wonder about
   - one thing the group could do to improve the poster

   After all of the posters have been seen, review the feedback from all of the groups.

PEST MANAGEMENT RESEARCH PROJECT

REVIEW

Refer to the questions that the students used in their research, and ask them:

- ***Name some of the pests you have researched.***
- ***Why are these organisms considered pests?***
- ***What are some of the programs that are being used to manage these pests?***
- ***What would happen to our crops if these pests were not managed?***
- ***How do these pests and their management programs affect the overall environment?***

SUMMARY

Agricultural pests and their management are a constant struggle for farmers who work to provide our food. While there are usually many different ways to manage pests, farmers also need to look at what effect the pests and their management practices have on the overall environment.

EXTENSIONS

Students could do one or more of the following activities:

1. Choose a pest that might be found in or around their homes and use the questions from this activity to describe how that pest could be managed.
2. Make a list of pesticides they find at home and indicate for which pests they are most effective.
3. Write a story about a crop from the perspective of the pest.
4. Participate in a virtual farming computer simulation or tour. Journey 2050 is a curriculum-based school program that takes students on a virtual simulation to explore world food sustainability. www.journey2050.com
5. Use Google Earth to survey the crop production areas in your home county/district. Through observation, try to determine the most common crop and which tillage method is used.

UP NEXT

Now that we have examined some ways farmers try to manage pests, let's explore some ways that farmers are trying to solve a particularly challenging problem in citrus plants.

Some pests are easy to see, but farmers can use small magnifying lenses to find harder-to-see pests.

PEST MANAGEMENT RESEARCH PROJECT

RESOURCES

- *Agricultural News Website*
  https://agfax.com
- *Agricultural Pests - UC IPM crop lists showing pests that affect each crop*
  http://ipm.ucanr.edu/PMG/crops-agriculture.html
- *Cooperative Agricultural Pest Survey – Pest Lists*
  http://caps.ceris.purdue.edu
- *Hungry Pests – USDA*
  www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/?utm_campaign=crosby-2017&utm_source=hungrypests-com&utm_medium=redirect&utm_keyword=home
- *Pest Tracker*
  www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/Pest-Tracker?utm_campaign=crosby-2017&utm_source=hungrypests-com&utm_medium=redirect&utm_keyword=/the-spread
- *Plant Pests and Diseases Programs*
  www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases
- *Pesticide Management Education Program – Cornell University*
  pmep.cce.cornell.edu
- *Definition of "environmental footprint"*
  https://dictionary.cambridge.org/us/dictionary/english/environmental-footprint
- *The carbon footprints of food production*
  www.researchgate.net/publication/228649298/download
- *Classroom-Ready Lessons for Agriculture Instruction*
  www.agednet.com
  - FM141 - Choosing A Tillage System To Save Soil and Reduce Costs
  - BT128 - Using Biotechnology To Alter, Control and Improve Plant Production
  - BT118 - Biotech: The Environmental Benefits
- *The nitrogen fix (Science Magazine)*
  https://science.sciencemag.org/content/353/6305/1225
- *Pesticide Half-life Fact Sheet*
  http://npic.orst.edu/factsheets/half-life.html
- *UC IPM - Birds, mammals and reptiles (Vertebrate pests)*
  http://ipm.ucanr.edu/PMG/menu.vertebrate.html
- *Plant Diseases (National Program)*
  www.ars.usda.gov/crop-production-and-protection/plant-diseases/
- *Carbon Sequestration in Soils*
  www.esa.org/esa/wp-content/uploads/2012/12/carbonsequestrationinsoils.pdf
- *A Method to Measure the Environmental Impact of Pesticides*
  https://ecommons.cornell.edu/handle/1813/55750
- *The nitrogen cycle*
  www.sciencelearn.org.nz/resources/960-the-nitrogen-cycle

STUDENT WORKSHEET

ACTIVITY 2: PEST MANAGEMENT RESEARCH PROJECT

Group Members ______________________________ Pest ______________

Use the tables below to collect data for your poster.

PEST		
Description of Pest	**Native/Non-Native (Where it came from and how it got here)**	**Life Cycle Most Dangerous to Crop**
Crop(s) Affected	**Damage to Crop**	**Number of Individual Pests Present to Significantly Harm Crop**

PEST MANAGEMENT OPTIONS			
Management Method	**Environmental Impact**	**Effectiveness**	**Data Source(s)**

Best possible management solution(s). ______________________________

____

____

Note any data you find about the environmental impact of the best management solution(s), using **+** for positive impact, **—** for negative impact and **0** for no impact.

Air Quality	________	Pollinators	________	Human Health	________
Biodiversity	________	Wildlife	________	Surface Water	________
Groundwater	________	Soil Fauna	________	Irrigation	________
CO_2 Emissions	________	Estuaries	________	Fossil Fuels	________
Waste	________	Methane Emissions	________	Desertification	________
Sustainability	________	Government Policy	________	Flora	________

BACKGROUND INFORMATION

PART 2

What is Citrus Greening?

Citrus greening (caused by the bacterium *Candidatus* Liberibacter asiaticus) is one of the most serious citrus plant diseases in the world. It is also known as Huanglongbing (HLB) or yellow dragon disease. Once a tree is infected, there is no cure. While the disease poses no threat to humans or animals, it has devastated millions of acres of citrus crops throughout the United States and abroad. Citrus greening is spread by a bacteria-infected insect, the Asian citrus psyllid (*Diaphorina citri* Kuwayama or ACP), and has put the future of America's citrus at risk. Infected trees produce fruits that are green, misshapen and bitter, unsuitable for sale as fresh fruit or for juice. Most infected trees die within a few years.

Global History

1919	First reported in southern China
1921	First report of disease in the Philippines, but it was thought to be related to zinc deficiency
1928	A disease named "yellow shoot" or "greening," depending on region, was observed in South Africa
1937	The first description of HLB in South Africa was assumed to be mineral toxicity
1941-1955	Most extensive work on greening in southern China was conducted
1956	Lin Kung Hsiang (researcher from China) concluded that greening is a graft transmissible infectious disease, not related to physiological disorders (e.g. nutrient deficiencies, water logging, etc.) or soil borne diseases (e.g. phytophthora, etc.)
1960's	HLB first appeared in Thailand
1965	Researchers in South Africa demonstrated HLB was transmissible by graft inoculation and by the African citrus psyllid, *Trioza erytreae*
1967	Philippine researchers demonstrated 'mottle leaf' or 'citrus dieback' could be transmitted by the Asian citrus psyllid, *Diaphorina citri*
1995	The official name of the disease became huanglongbing (HLB) at the International Organization of Citrus Virologists (IOCV) at the 13th conference of the Organization in Fuzhou (Fujiam, China)
1998	Asian citrus psyllid arrived in Florida
2004	The disease was confirmed to be in Brazil
2005	The disease was confirmed to be in Florida
2012	First occurrence of Asian citrus psyllid/HLB in California
2017	The disease was confirmed to be present in California citrus

Florida History

2005	August - Citrus greening was first confirmed in south Miami-Dade county
	October 25 - Four counties confirmed positive (Dade, Broward, Palm Beach, Hendry)
	September 16 - Federal order issued to restrict the interstate movement of all citrus greening and Asian citrus psyllid host plant material from Florida's quarantined areas
2006	March 14 - Regulations for citrus nurseries were established
2007	December - Federal order issued was revised to include all counties with confirmed greening
2008	January 11 - Federal order issued to quarantine the entire state of Florida
	August 7 - Thirty-two counties confirmed positive (Sumter)
2009	February 16 - Thirty-three counties confirmed positive (Putnam)
2018	HLB is known to be present in all citrus growing areas of Florida

Timeline from the University of Florida **https://crec.ifas.ufl.edu/extension/greening/history.shtml**

BACKGROUND INFORMATION

Pathogen

Candidatus Liberibacter species are phloem-limited plant pathogens that are mainly transmitted to plants by psyllids. An infected psyllid feeds on a healthy tree and injects the bacterium into the **phloem**. Plant food sugars are made by photosynthesis and are carried through its phloem system bidirectionally to flowers, fruits, roots, and seeds. Once a tree is infected with the bacterium, there is no known cure for the disease. This is partly because the bacterium is inside the vascular system of the plant (systemic) and is therefore very difficult to access.

Diagnosis

The first sign of the disease is leathery leaves with yellow veins and blotchy marks, and the fruit remains green. Polymerase chain reaction (PCR), a common laboratory technique used to make many copies of a particular DNA region, is one way to positively confirm citrus greening.

Dogs have been trained to efficiently sniff out the bacterium *Candidatus* Liberibacter asiaticus in infected plants. The trained dogs can distinguish the citrus greening bacteria from other similar bacteria, resulting in highly reliable detection. While the number of trained dogs is currently limited, it is expected that they will eventually be used for early detection in all citrus-producing states.

Management Approach

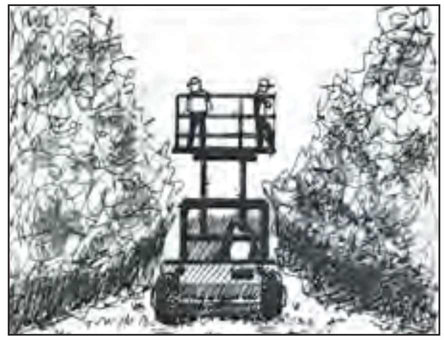
There are several management approaches currently in various stages of use and/or development. Groves can be managed:

- as if they already have greening with an integrated approach using disease-free nursery stock.
- by reduction of the inoculum by frequent disease surveys.
- by removal of symptomatic trees.
- by suppression of the Asian citrus psyllid.

Pruning only symptomatic (diseased) branches is ineffective. Tree removal, including the stump and roots, is the only way to ensure that infected trees will not spread the disease to other trees. New citrus trees (which should not be planted in the same area as the infected tree[s]) should be purchased from a certified nursery or propagated from clean bud wood.

Scouting (monitoring) is recommended four times a year, unless a grove already has greening. If there is currently greening in a grove or close by, scouting more than four times a year is recommended. Symptoms are most easily seen from September through March. During the spring growth, scouting becomes more difficult and scouts have to look further into the tree canopy. Scouting methods include using a tractor or pickup mounted platform (for taller trees), ATV's (for medium-sized trees), or walking (for young trees).

Scouting for Citrus Disease



Grove conditions also affect pest management. Scouting is more difficult in a grove that has not been well-maintained. Nutritional deficiencies can cause greening symptoms to blend and go unnoticed. Excessive weeds and unmanaged areas in between the rows of trees cause scouts to watch where they are walking more than scouting. Tree size increases scouting work as well.

In the United States, trees that appear to have citrus greening are identified with a special tape (used only to identify the citrus greening disease) that is attached to the suspected branch; the tape is marked with the inspector's name and date. Ideally, scouts mark the end of the row and the number of suspect trees in that row. Safety concerns include grove conditions, chemical spray applications, weather, and potential for slips and falls.

ACTIVITY 3: CITRUS GREENING MANAGEMENT

(Advanced Activity)

TIME Three 45-Minute Class Periods

ACTIVITY AT A GLANCE

Students will research the cause of citrus greening disease and the different methods that are being used to control the disease.

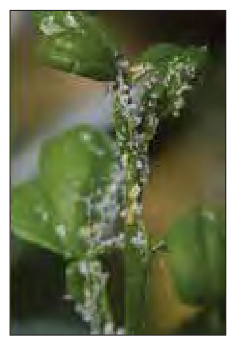
TIME TO TUNE IN

Bitter Fruit - Citrus Greening Disease Threatens Florida Industry (2:52)
www.youtube.com/watch?v=T5nqVmliUaM

Citrus Greening Disease! (9:10)
www.youtube.com/watch?v=G_1sobDdtiM

Lyle Buss, UFL IFAS

Asian citrus psyllid adult.



Lyle Buss, UFL IFAS

Asian citrus psyllid nymphs; note the white honeydew and the leaf distortion.

Timothy Gotwald, USDA ERS

"Zinc-pattern-deficiency" interveinal chlorosis symptoms.

Timothy Gotwald, USDA ERS

Asymmetrical "lopsided" sweet orange fruit.

CITRUS GREENING MANAGEMENT

GETTING STARTED

MATERIALS

- **Citrus Greening Disease** worksheet
- **Citrus Greening Management Programs Data Table**
- **Credible Source Guide**
- A small box that contains individual slips of paper that show the names of different disease management programs.
- Internet Access

ADVANCE PREPARATION

1. Divide the class into small groups of 2 or 3 students
2. Secure internet access
3. Make a copy of the following materials for each group: **Citrus Greening Disease** worksheet, **Citrus Greening Management Programs Data Table** (3 copies), and **Credible Source Guide** – one for each group.
4. Write the names of various citrus greening management methods on slips of paper and place them into a small box.

   Suggested Management Programs (complete list on pages 103-104)
   - Tenting and Steaming
   - Nutrition Programs
   - Parasitic Wasps
   - Reflective Mulch
   - Bactericides
   - Citrus Under Protective Screens (CUPS)
   - Disease-resistant Trees
     - by traditional breeding
     - or by GE methods (rDNA or genome editing)
   - Insecticides
   - GE Virus

INTRODUCTION

This is the third activity in this module. In the first activity, students created a working definition of an agricultural pest. In the second activity, students researched certain agricultural pests. In this activity, students will research citrus greening disease and the management programs that are currently used to try to address the disease.

STUDENT PROCEDURE

1. Review your definition of agricultural pest from Activity 1 and the different pest management methods studied in Activity 2.
2. You will research the pest that causes citrus greening disease and the different programs being used to try to manage the disease.
3. Watch *Bitter Fruit - Citrus Greening Disease Threatens Florida Industry* - www.youtube.com/watch?v=T5nqVmliUaM

   and *Citrus Greening Disease!* - www.youtube.com/watch?v=G_1sobDdtiM
4. As you watch the videos, answer the questions on the **Citrus Greening Disease** worksheet and then share your answers after viewing the video.
5. Ask one person in your group to pick one of the different disease management programs from the slips in the small box. Each group will research that program and present their findings to the class in a 3-minute presentation.
6. Make sure that everyone in your group has a **Citrus Greening Management Programs Data Table** sheet. Review the information you will need to include in your report. Use the **Credible Source Guide** during your research.
7. As each group makes their presentation, the other groups should complete the **Citrus Greening Management Programs Data Table** with information they have learned from the presentations. After all of the presentations have been made, the groups could debate which management program is the most effective and why, using their Data Tables as references for their explanations.

CITRUS GREENING MANAGEMENT

REVIEW

Ask your students to reflect on the impact agricultural pests have on our food supply. If they could ask researchers to focus on one pest problem, what would it be and why would they choose that one?

SUMMARY

Agricultural pests need to be managed effectively so we have an adequate food supply and adverse impacts on the environment from pest management tools are limited.

EXTENSIONS

Students could do one or more of the following activities:

1. Create a story book (for 5th grade level, middle school students) about citrus greening disease and its management.
2. Make a list of what people can do to manage the pests in their environment.
3. Make a 30-60-second commercial on how people can manage pests in their environment.

UP NEXT

Now that you've learned about environmental pests and ways farmers try to manage them, let's take a look at strategies to enhance nutrients in food for humans and animals.

RESOURCES

- *Citrus Research Board*
  https://citrusresearch.org/
- *Biological Control for the Asian Citrus Psyllid* – describes parasitic wasps
  www.youtube.com/watch?v=iHpmJy0Bq7M
- *Citrus Greening Disease!*
  https://www.youtube.com/watch?v=G_1sobDdtiM
- *Breakthrough made in citrus greening research*
  https://www.theledger.com/news/20190916/breakthrough-made-in-citrus-greening-research
- *Dozens of Trees with Incurable Disease Found in Pico Rivera*
  www.whittierdailynews.com/2017/12/18/dozens-of-trees-with-incurable-disease-found-in-pico-rivera/
- *Questions and Answers – Draft Environmental Impact Statement and Preliminary Pest Risk Assessment for Permit for Environmental Release of Genetically Engineered Citrus Tristeza Virus*
  www.aphis.usda.gov/brs/aphisdocs/17_044101r_CTV_Q&A_April2019.pdf
- *Metalized Reflective Mulch a Bright Spot for Citrus*
  www.growingproduce.com/citrus/insect-disease-update/metalized-reflective-mulch-bright-for-citrus

STUDENT WORKSHEET

ACTIVITY 3: CITRUS GREENING DISEASE

Name ______________________________ Date ____________ Class/Hour __________

Answer the following questions as you watch these two videos:
Bitter Fruit - Citrus Greening Disease Threatens Florida Industry www.youtube.com/watch?v=T5nqVmliUaM and
Citrus Greening Disease www.youtube.com/watch?v=G_1sobDdtiM.

1. What is citrus greening disease and what are its symptoms? ______________________________

2. What is the name of the bacterium that causes the disease? ______________________________

3. How does the disease spread in a citrus grove? ______________________________

4. How widespread is this disease in the United States? ______________________________

5. Which groups of people are impacted by citrus greening disease? ______________________________

6. What is the research objective of the scientists' work in the video? ______________________________

7. What is the hypothesis for their research? ______________________________

8. What happens to the bacterium in the body of a psyllid that enables it to be transmitted from one citrus tree to another? ______________________________

9. List the 4 steps in the Detached Leaf Transmission Assay. ______________________________

10. How do the scientists detect the bacteria in the infected leaves and why do they use this method? ______________________________

11. What did the scientists learn through their research? ______________________________

12. What do the scientists hope to eventually be able to do with their information? ______________________________

13. Why do you think this research is important? ______________________________

14. If you could use Genetic Engineering to create a way to control HLB, what would you design, and which pest control method would it use? ______________________________

CITRUS GREENING MANAGEMENT PROGRAMS DATA TABLE

Management Program	Management Description	Effectiveness of Treatment	Environmental Impact	Part of Tree Treated	Where Used and Frequency

MODULE 4

BIOTECHNOLOGY AND NUTRIENTS

This module introduces some aspects of biotechnology related to enhancing nutrient availability for plants, animals, and humans.

For this module, it is recommended that teachers will have already taught an introduction to nutrition, macronutrients, micronutrients, and basic selective breeding and genetic engineering.

BACKGROUND INFORMATION

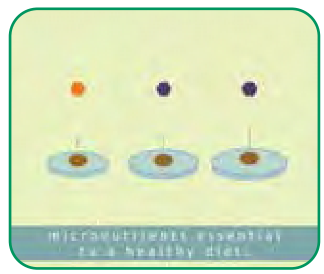
This section examines how some strategies such as selective breeding (introduced in Module 1) and genetic engineering (introduced in Module 2) can be used to enhance nutrient availability.

ACTIVITY

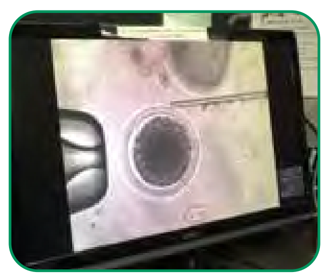
Nutrient Supply will teach students to identify ways to enhance nutrient availability for a specific nutrient in a human population that struggles to meet their nutrition needs.

TIME TO TUNE IN

Biofortification: It All Starts With A Seed (2:42)
https://www.youtube.com/watch?v=kSzHCDtJ_v0



Gene editing promises to boost nutrition in foods (2:19)
www.youtube.com/watch?v=P3OLwTfTRhY



How Can CRISPR Improve Food? (3:32)
www.youtube.com/watch?v=tyNynnKECBs&t=21s

BACKGROUND INFORMATION

The first two modules in this Teacher's Guide introduce key agricultural methods, particularly selective breeding and genetic engineering. Modules 3 and 4 highlight some of the major reasons *why* we use these techniques (e.g., to decrease pest damage, to enhance nutrient profile).

All living things (plants, animals, and humans alike) need nutrients to survive. Nutrients in food contribute to cell-building and structural materials, regulate important functions in living tissues, and provide energy for growth and health. Nutrients are categorized as macronutrients (proteins, carbohydrates, and fats) or micronutrients (vitamins and minerals). Macronutrients are consumed/required at greater levels (g), micronutrients at lower levels (mg or µg). An "essential" nutrient is a nutrient that a plant, animal, or human must obtain from another source, because that organism cannot make it or cannot make enough of it for good health.

Human Nutrition

Every 5 years, human nutrition experts from different parts of U.S. society, including academia and government, review the latest nutrition information and issue a report called the *Dietary Guidelines for Americans* to promote good health. These *Guidelines* identify:

- target dietary goals for key micronutrients and macronutrients
- nutrients that Americans typically should aim to get more of (e.g., fiber, Vitamin D, calcium, potassium, iron)
- nutrients that people should aim to get less of (e.g., sodium, saturated fat, added sugars).

Key nutrients are shown on Nutrition Facts labels to help people make healthy food choices. For a more detailed supplementary curriculum on nutrition, see *Science and Our Food Supply: Using the Nutrition Facts Label to Make Healthy Food Choices*.

Essential nutrients for human diets are shown below. The exact amount recommended for individual people varies by age and sex, as well as with specific health conditions. For recommended nutrient intake for healthy individuals, see *Dietary Reference Intakes for Macronutrients, Vitamins and Micronutrients.*

Essential Nutrients for Humans

Macronutrients		Micronutrients	
Amino acids	**Fatty acids**	**Vitamins**	**Minerals**
Histidine	Linoleic acid	A	Ca (Calcium)
Isoleucine	Alpha-linolenic acid	B_1 (Thiamin)	Cl (Chlorine)
Leucine		B_2 (Riboflavin)	Cr (Chromium)
Lysine		B_3 (Niacin)	Cu (Copper)
Methionine		B_5 (Pantothenic acid)	Fe (Iron)
Phenylalanine		B_6	Fl (Fluoride)
Threonine		B_7 (Niacin)	I (Iodine)
Tryptophan		B_9 (Folate)	K (Potassium)
Valine		B_{12}	Mg (Magnesium)
		C (Ascorbic Acid)	Mn (Manganese)
		D	Mo (Molybdenum)
		E	Na (Sodium)
		K	Ni (Nickel)
		Choline	P (Phosphorus)
			S (Sulfur)
			Se (Selenium)
			Zn (Zinc)

BACKGROUND INFORMATION

Toxins and Anti-Nutrients

In addition to making many desirable nutrients, plants make toxins. They adjust their biochemistry to adapt to their environment, including defending themselves from predators. If consumed in sufficient quantities, some toxins can affect human or animal health. Through domestication, agriculturally important crops (including tomatoes and potatoes) have been bred to eliminate or reduce the level of relevant toxins. The word toxin is sometimes used to indicate substances of biological origin with toxic properties. These are also often referred to as toxicants.

Major toxins and their effects:

- Cyanogenic glycosides in cassava, sorghum, and bamboo shoots that are improperly prepared can result in unsafe levels of cyanide toxins harmful to people and/or animals.
- Curcubitacin in cucumber and squashes can cause acute gastrointestinal effects.
- Glycoalkaloids (e.g., solanine) in potatoes may induce gastrointestinal and systemic effects if consumed in high amounts. Potatoes/potato byproducts (e.g., skins where glycoalkaloids are concentrated) that are high in glycoalkaloids can be fatal for animals.
- Psoralen, a furocoumarin produced by some plants (celery and parsnips) that can harm the skin of people working in the sunlight.
- Coumarin (normally in sweet clover) can be metabolized by some fungi into dicoumarol, which causes prolonged clotting time and bleeding disease in cattle (rarely in horses).

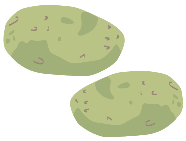
Plants also make substances that can affect the ability of human and animal digestive systems to extract the most nutrients out of food. These are called **anti-nutrients**.

Some major anti-nutrients and their effects:

- Glucosinolates in cruciferous vegetables can prevent iodine absorption.
- Lectins in legumes and whole grains can inhibit calcium, iron, phosphorous, and zinc absorption.
- Oxalates in leafy green vegetables and teas can inhibit calcium absorption.
- Phytates (phytic acid) in whole grains, seeds, legumes, and some nuts can decrease the bioavailability of iron, zinc, magnesium, and calcium.
- Saponins in legumes and whole grains can interfere with some nutrient absorption.
- Tannins in tea, coffee, and legumes can decrease iron absorption.

Human nutrition experts use dietary reference intake values to decide how much of a given nutrient people should consume (on average). These values include the adequate intake, recommended daily allowance, and tolerable upper limit for specific subgroups. Whether a substance is considered toxic depends on the dose (amount) consumed. The tolerable upper limit for an infant would be less than the limit for a grown adult, since the amount taken per body weight would be much higher for the infant. However, many desirable nutrients (including water) can be considered toxic if overconsumed. The phrase often used to describe this reality is "The dose makes the poison."

How Much is Too Much?



A 100-pound person would have to eat a pound or more of totally green potatoes to show low-grade symptoms of toxicity (nausea, diarrhea, vomiting).

Water needs vary with activity level. People also get water through various foods they eat. On an average day, adult men need 3.7 liters of water; adult women need 2.7 liters of water; and teenagers need about 2 liters. But, kidneys have a limit on how much water they can process each hour. Although highly unusual in healthy people, rapidly drinking excessive amounts of water can cause low sodium levels that lead to headaches, diarrhea, nausea, vomiting, and impaired brain function. Extreme overconsumption can be fatal.

Nutrient Deficiency

Throughout history, there have always been some people who had diseases and ailments associated with nutrient deficiency or malnourishment. Malnourishment is typically caused by a lack of access to enough nutritious food because of poverty, war, climate or weather conditions, and other economic factors. Circumstances that make it uncertain whether nutritionally adequate and safe food is available in socially acceptable ways is also called "Household Food Insecurity." Historically, the typical image of hunger was often an emaciated or very underweight person who also suffered from poverty. Today, hunger is still a problem, but the number of people who are both malnourished and overweight or obese has increased.

BACKGROUND INFORMATION

Fortified Bread Saves the South

In the late 1800s and early 1900s, hundreds of thousands of people (mostly poor) in the southern United States were suffering from the disease known as pellagra. Over 150,000 people died from pellagra in the early 1900s, while others suffered with untreatable symptoms from the disease known as the Four D's: depression, dermatitis, diarrhea, death. For decades, it was unknown what caused pellagra, but many scientists thought it was linked to the corn-rich diet of the south. Dr. Joseph Goldberger, a Hungarian immigrant and epidemiologist, believed that pellagra was a diet-related disease. It was later discovered, after his death, that nicotinic acid (more commonly known as the vitamin 'niacin' or 'vitamin B_3') was lacking in the diets of those suffering from pellagra. Much of the corn consumed in the southern United States was degerminated (processed to remove the germ portion of the corn kernel); the germ portion contains niacin.

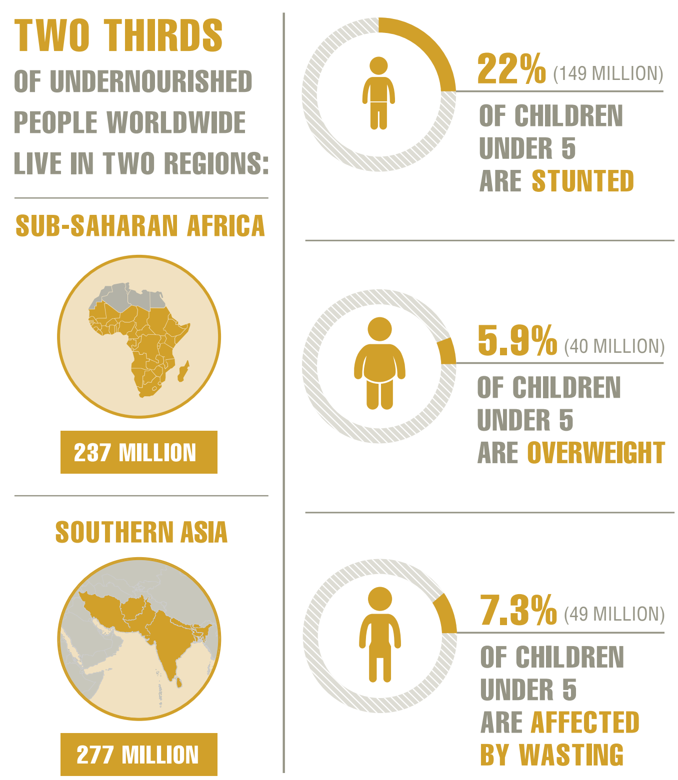
In 1940, the FDA held the "flour hearings," and a team of scientists, doctors, and the Surgeon General worked tirelessly to propose adding thiamin, riboflavin, and niacin to bread. Cornbread and white breads lacking certain nutrients would be "enriched" with a fortified vitamin-rich flour. Enriched (fortified) white bread caused pellagra to virtually disappear overnight.

In February 2018, the World Health Organization (WHO) cited that about 1.9 billion people on earth were estimated to be overweight or obese, whereas almost half a billion people were estimated to be underweight. According to the United Nations, more than 1 in 10 people do not get enough to eat and 1 in 3 people are malnourished. Around 45% of deaths among children under 5 years of age are linked to undernutrition, mostly occurring in low- and middle-income countries. At the same time in these countries, rates of childhood overweight and obesity are rising. Although there is an increase in obesity, many of those people are also undernourished – a condition known as **hidden hunger.**

Women, infants, children, and adolescents are at highest risk of malnutrition. From conception to a child's second birthday, it is important that infants have access to nutrient-dense foods to ensure the best start in life, with long-term benefits.

Malnutrition (WHO definition)
Malnutrition, in all its forms, includes undernutrition (wasting, stunting, underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related noncommunicable diseases.

Hidden Hunger (WHO definition)
Hidden hunger is a lack of vitamins and minerals. Hidden hunger occurs when the quality of food people eat does not meet their nutrient requirements, so the food is deficient in micronutrients such as the vitamins and minerals that they need for their growth and development.



From the United Nations

Poverty can be one of several contributors to malnutrition. Malnourishment increases healthcare costs, reduces productivity, and slows economic growth, perpetuating a cycle of poverty and poor health. Malnutrition impacts every country in the world in some form and fighting malnutrition is one of the biggest global health challenges today. The United Nations is committed to an initiative known as "Zero Hunger by 2030." For more about this initiative, see www.fao.org/resources/%20infographics/infographics-details/en/c/1003923/.

BACKGROUND INFORMATION

Agricultural Methods to Enhance Nutrient Availability

The problem of malnutrition is complex and solving it will require an integrative approach that combines various public health interventions, such as providing oral supplementation, nutrition education, access to nutritious foods, and improving the nutritional composition of food. Various approaches have been used to help optimize nutrient intake for plants, animals, and people, as well as to minimize toxins and anti-nutrients.

Agricultural methods include:

- Selective breeding without molecular biology techniques to assist plant or animal selection
- Selective breeding with molecular biology techniques to support plant or animal selection
- Genetic engineering (GE) tools

Each of these is used to enhance plant nutritional profiles.

Nutrient Enhancement

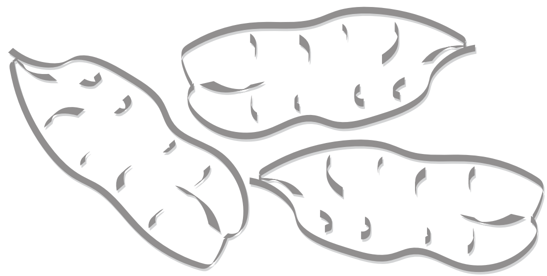
Traditionally, many techniques were employed to enrich the nutrient density of food. Nutritional value that is changed during the processing of food crops (post-harvest) is called **fortification**. Breads that have added riboflavin, thiamin, and niacin are examples of fortification.

Newer technologies, known as **biofortification,** include the use of plant breeding methods (both conventional plant breeding methods and GE tools) to increase the levels of certain key nutrients in foods. Through biofortification, staple food crops, such as rice and cassava, are developed to obtain varieties with higher levels of a single or several nutrients and improved agronomic traits (e.g., high-yield). Biofortification is a way to reach populations where conventional (post-harvest) fortification can be difficult to implement with little or no processing of crops, or for people who may have limited access to commercially fortified products.

Examples of biofortification projects include:

- Iron-biofortification of rice, beans, sweet potato, cassava, and legumes
- Zinc-biofortification of wheat, rice, beans, sweet potato, and corn
- Provitamin A carotenoid-biofortification of rice, sweet potato, maize, and cassava
- Amino acid and protein-biofortification of maize, sorghum, and cassava

To date, most crops with enhanced nutrient profiles have been developed using selective breeding without GE tools.



Biofortification of the Sweet Potato in Uganda

Many people in Uganda are Vitamin A deficient. Vitamin A deficiency (VAD) lowers immunity, impairs vision, and may lead to blindness and even death. In Uganda, 32% of children under 5 years old are estimated to be Vitamin A deficient. Annually, Uganda loses about 145 million dollars to vitamin and mineral deficiencies (World Bank, 2009). To fight against this epidemic, researchers studied the typical Ugandan's diet to determine how to increase their overall intake of Vitamin A.

People of Uganda traditionally eat a white-fleshed sweet potato that lacks Vitamin A. Through conventional selective breeding, the orange-fleshed sweet potato was bred to be rich in Provitamin A carotenoid (beta-carotene), which is a precursor to Vitamin A, as a replacement for the white-fleshed potato in the diets of the people of Uganda. The successful integration of this new crop into Ugandan's diets was the result of key collaboration among scientists, the government, farmers, and the people of Uganda.

Farmers were taught how to grow this new sweet potato variety that was also well-suited for the environment. In addition, technical support was provided for processing, storing, and packaging this crop. The people of Uganda were educated about how this orange-fleshed sweet potato could help to improve their lives. Events like music concerts, community outreach programs, films, and community leader endorsements took place to promote its use. The sweet potato was poised as a delicious and healthier alternative that could be incorporated into many traditional and new dishes.

These efforts all contributed to the success and the bright future of the Vitamin A biofortified sweet potato in Uganda.

BACKGROUND INFORMATION

GE Methods of Nutrient Enhancement

Scientists can employ multiple GE methods to develop new plants with enhanced nutritional content. The genetic tools used to increase nutrient content include:

- Increasing gene expression, by increasing gene copy number or by manipulating gene promoter activity
- Adding genes to bridge gaps in a biosynthetic pathway (e.g., Golden rice that contains beta-carotene, a precursor of Vitamin A) or to create new biosynthetic pathways (e.g., omega-3 canola)
- Promoting the expression of transcription factors to turn on innate but inactive biosynthetic pathways in different plant tissues or at different developmental stages (e.g., anthocyanin in tomatoes).

While few nutrient-enhanced plant varieties are currently available, this may change as many are under development.

It's important to know that plants developed for a specific nutritional purpose may also impact the availability of another nutrient. For example, a crop engineered to produce oil with more of the essential fatty acid, linolenic acid (omega-3 fatty acid), could have less of the essential fatty acid, linoleic acid (omega-6 fatty acid).

Some GE crops are in development with increases in multiple nutrients. Spanish researchers have created an African corn variety with 169 times more beta-carotene, 6 times more vitamin C, and twice as much folate. A GE sorghum variety produced by the Biofortified Sorghum Project for Africa has increased levels of beta-carotene, iron, zinc, and essential amino acids. Crops like these may help reduce malnutrition in underdeveloped countries.

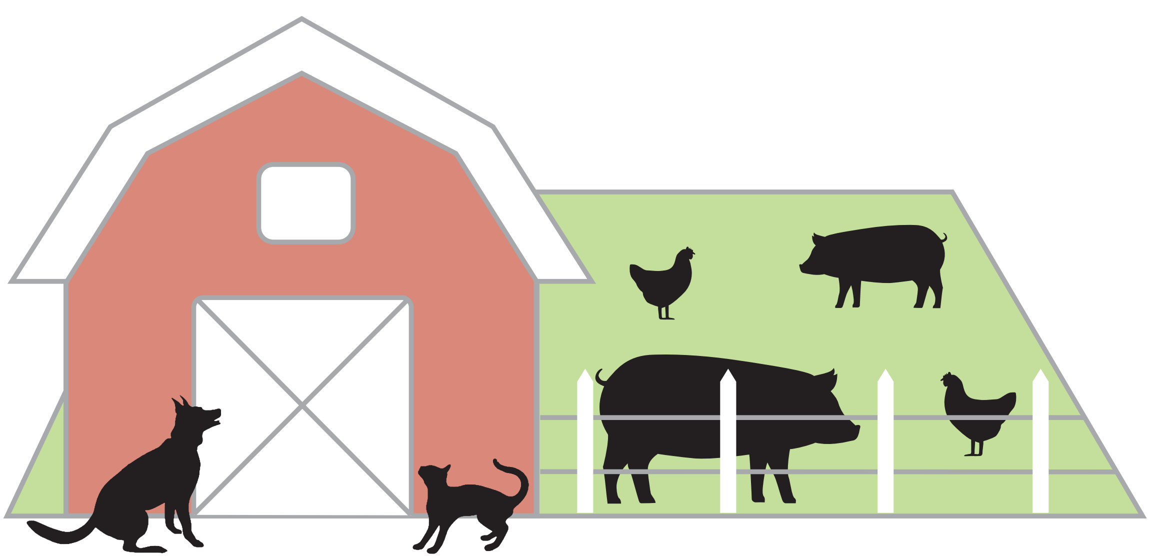
Animal Food

Animals typically eat the same or similar diets their entire lives, and the nutrient requirements for each animal species during each life stage (e.g., pregnancy, lactation, growth, aging) and production conditions (if applicable) have been identified. Although the nutrient requirements (amino acids, fats, oils, carbohydrates, fiber, vitamins, and minerals) are usually defined, animal diets are made from several ingredients including whole grains, oilseeds, by-products of human food production, vitamins, and minerals.

Animal food includes crops cultivated through selective breeding for their nutrient content and can also be supplemented with other ingredients that fortify the food with important amino acids and other essential nutrients needed in animal diets. Periodically, animal nutritionists will review the latest nutrition information and provide guidance on the levels of nutrients that are required to promote good health. Plant breeders try to optimize nutrients in plants consumed by animals using similar approaches to those used to optimize plants for human nutrition.

What's Safe or Unsafe to Eat Differs by Species

Many people enjoy chocolate and cook or season their food with onions and garlic. However, each of these typical human diet items contain substances that can harm cats, dogs, and other animals. If they eat too much of them, it could cause sickness or death.



BACKGROUND INFORMATION

Plant Nutrients - Focus on Nitrogen

Plants get some of their essential nutrients from the air and some from the soil in which they grow. Plants absorb carbon, oxygen, and hydrogen from the air. The three main nutrients they obtain from the soil are nitrogen (N), phosphorus (P), and potassium (K), often referred to as the trio NPK. Some scientists are researching methods to give major crops the ability to "fix" nitrogen from the air into a biochemically usable form. Nitrogen fixation is currently limited to certain microbes, and it is essential to life. Fixed nitrogen is a key ingredient in important biomolecules, including amino acids, which are the building blocks of proteins.

Farmers currently add nitrogen to their crops by applying fertilizer or by planting legumes, which host nitrogen-fixing bacteria in their roots. Altering cereal grain crops to produce their own nitrogen would be an achievement for biotechnology, and this could help solve two big problems: The overuse of fertilizer, which can pollute aquifers or water bodies, and the shortage of fertilizer experienced by small farmers in the developing world.

Varied International Approaches

Internationally, crops developed using GE tools are usually referred to as "genetically modified," GMOs, or bioengineered (BE). As of 2017, 17 million farmers in 24 countries report producing over 469 million acres of "genetically modified" crops. Although many countries are producing crops that include GE plants, many more import GE crops for use in food for humans and animals. Various countries adhere to different policies and legislation regarding current production, import, and export of genetically modified crops. For an overview of GE crops by country, see *ISAAA: 22 Years of Biotech Crops in the World:* **http://www.isaaa.org/resources/infographics/22yearsofbiotechcrops/22%20Years%20of%20Biotech%20Crops%20in%20the%20World.pdf**

Select Nutrient-modified GE Plant Varieties*	
Canola	Laurical™ - more lauric acid
	Phytaseed™ - increases phosphorus availability in animal food
Corn/maize	Mavera™ - increases production of the amino acid lysine
Rice	Golden Rice – contains beta-carotene (provitamin A)
Soybeans	Treus™, Plenish™ - less polyunsaturated fat (linoleic and linolenic acid), more monounsaturated fat (oleic acid)
	Vistive Gold™ - less polyunsaturated fat (linoleic acid), less saturated fat (palmitic acid), more monounsaturated fat (oleic acid)
Pineapple	Rosé – increased lycopene
Purple tomato	Increased anthocyanins in the fruit

*Check the ISAAA website for up-to-date regulatory status globally.

Source: **www.isaaa.org/gmapprovaldatabase/commercialtrait/default.asp?TraitTypeID=4&TraitType=Modified%20Product%20Quality%20in%20the%20World.pdf**

NUTRIENT SUPPLY ACTIVITY

TIME Two 45-Minute Classes

ACTIVITY AT A GLANCE

In this activity, students will explore the global problem of nutrient availability and techniques that are being used to improve nutrient supplies where shortages exist. Students will also exercise their ability to identify credible information sources.

TIME TO TUNE IN

Biofortification: It All Starts with A Seed (2:42)
https://www.youtube.com/watch?v=kSzHCDtJ_v0

Gene editing promises to boost nutrition in foods (2:19)
www.youtube.com/watch?v=P3OLwTfTRhY

How Can CRISPR Improve Food (3:32)
www.youtube.com/watch?v=tyNynnKECBs&t=21

GETTING STARTED

MATERIALS

- Hunger Map (World Food Programme)
  https://hungermap.wfp.org/ (updated annually)
- **Malnutrition Report** worksheet
- **Credible Source Guide**
- Internet access

ADVANCE PREPARATION

Students can work individually or in groups for this activity.

Determine how students will research malnourishment, nutrient availability, and website credibility. Since the information is only available online, it's essential that all students have access to the internet.

Print enough copies of the **Malnutrition Report** worksheet and **Credible Source Guide** for everyone in your class.

To introduce the topic of malnourishment and hidden hunger, consider providing two images: one of an obese individual and one of someone who is emaciated. Ask students how these two differ and what they have in common. The concept is that sometimes hunger is hidden, and although a person is obese, he or she may still be malnourished.

Remind students that there are several strategies/tools they can use to improve nutrient availability. Biotechnology includes a range of tools, such as selective breeding and genetic engineering (bioengineering).

NUTRIENT SUPPLY

INTRODUCTION

This lesson will focus on using credible sources to research efforts being made to improve nutrient availability. Ask these questions to introduce nutrition/malnutrition:

- **What does a malnourished person look like?**
- **How can you determine if someone is malnourished?**
- **Which countries in the world do you think have the most malnourished people?**
- Other than donating food to these countries, what could be done to help malnourished people?
- In the year 2030, 8.3 billion people will need to be fed. In this same year, the United Nations is committed to ensuring that no person is undernourished. How do you think this will happen?

STUDENT PROCEDURE

Day 1

1. Everyone should have their own copy of the **Credible Source Guide** and **Malnutrition Report** worksheet.
2. Use the internet to see the search engine results for "malnutrition." Hundreds, if not thousands, of web addresses should appear. Which ones are credible? Discuss the criteria for identifying credible sources as you begin your worksheet.
3. Refer to the Hunger Map as you begin your worksheet; choose a country to research that has one of the highest percentages of malnourishment (over 35% of the population).

Day 2

1. Use part of the class to finish your research and review your answers on the **Malnutrition Report** worksheet.
2. You will present (possibly by PowerPoint) your research to the class; your presentation will include:
   a. The selected country
   b. The staple crops that the people in this country consume
   c. The nutrient that people in this country lack
   d. The nutrient-enhanced foods that are available to be grown in this country
   e. Individual countries have their own laws and regulations governing use of biotechnology. If seeds for GE crops are made available to the country, do the regulations in the selected country permit their use by farmers? What is the process needed to obtain authorization for cultivation? For food use?
   f. A proposal to introduce this crop to the farmers and consumers of this country

REVIEW

1. ***How could a person be obese but also be malnourished?*** The quality of the diets of many obese people is deficient in micronutrients, such as vitamins and nutrients that are needed for proper growth and development. Although they take in more than enough calories, they lack foods rich in certain nutrients. This is known as hidden hunger.
2. ***How does poverty intensify the risk of malnourishment?*** People who experience poverty are more likely to be malnourished. Malnourishment increases healthcare costs, reduces productivity, and slows economic growth, which perpetuates a cycle of poverty and poor health. Malnutrition impacts every country in the world in some form.
3. ***How do fortification and biofortification of crops compare?*** Biofortification increases the nutrient levels during plant growth; the fortification process increases the nutrient levels during processing (post-harvest) of the crops. Biofortification has the benefit of reaching people in all areas of the world where processing and/or possible supplementation may be limited.
4. ***How has biotechnology impacted agriculture to provide more nutritional crops?*** Through selective breeding and genetic engineering, new crop varieties can be developed that have specific nutrient enhancements and that can be grown and readily accessible to the malnourished people of various countries. New crop varieties can also provide food choices with healthier nutrient profiles, such as oils with healthier fatty acid profiles.

NUTRIENT SUPPLY

EXTENSIONS

Students could do one or more of the following activities:

1. Develop an advertisement for one of the crops that could help to solve a specific nutrient deficiency. This can be a poster, a t-shirt, pamphlet, video, song, public service announcement, or another marketing tool to promote cultivation and consumption of this crop.
2. Create a poll to survey people in your school and/or community about hidden hunger and nutrient enhancement of crops as a solution. Create a graphic representation of your findings and present these to the respondents and the school in a way that educates them about these two issues.
3. Research a GE crop that is still under development (not commercially available) that has enhanced nutrient content that could improve human health. Write an editorial to state your opinion about this particular crop. State why the crop should or should not be grown and used; include at least five sources as evidence for your viewpoint.

SUMMARY

Hunger and undernutrition, in some form, exist in every country of the world. By the year 2030, the world will be populated with an estimated 8.3 billion people, and the United Nations' goal is that not one person will be undernourished.

Through agricultural methods, including selective breeding and genetic engineering, staple crops can be nutritionally enhanced to have higher levels of nutrients to improve human and animal health. A limited number of GE crops are commercially available; however, several crops that have been nutritionally enhanced are in production or being used.

UP NEXT ▶ ▶ ▶

Now that we've considered some ways to enhance crop nutrient quality, let's learn how new plant and animal varieties are evaluated for safety.

RESOURCES

ISAAA Pocket K No. 41: Nutritionally Enhanced GM Feed Crops
www.isaaa.org/resources/publications/pocketk/41/default.asp

Malnutrition (World Health Organization)
https://www.who.int/news-room/fact-sheets/detail/malnutrition

HarvestPlus: Knowledge Center
https://www.harvestplus.org/knowledge-center

Dr. Joseph Goldberger & The War on Pellagra
https://history.nih.gov/exhibits/goldberger/index.html

Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016.
www.ncbi.nlm.nih.gov/pubmed/28580239

Evaluating Credibility
http://guides.lib.byu.edu/c.php?g=216340&p=1428399

IFIC Fact Sheet: Benefits of Food Biotechnology
https://foodinsight.org/fact-sheet-benefits-of-food-biotechnology/

Biofortified Crops Generated by Breeding, Agronomy, and Transgenic Approaches Are Improving Lives of Millions of People around the World
www.ncbi.nlm.nih.gov/pmc/articles/PMC5817065/

Let Seed Be Thy Medicine (HarvestPlus)
https://vimeo.com/328702230/5f793b3d1f

The Poison is the Dose – Penn State
www.youtube.com/watch?v=THr7roac0cA

STUDENT WORKSHEET

MALNUTRITION REPORT

Name ______________________________ Date ____________ Class/Hour __________

1. How do you know that the Hunger Map (provided) is a credible source? ______________________________

____

2. Which countries exhibit undernourishment for greater than 35% of their population? ______________________________

____

3. Choose one of those countries for your report on malnutrition. Which country did you choose? Why? ______________________________

____

4. Sketch the shape of the country you chose and identify on which continent this country is located.

5. Describe the country's climate. ______________________________

____

6. Complete the chart below using the **Credible Source Guide**.

Question	Answer(s) From Your Research	Citation: Title/Website Address
a. Identify one nutrient that this country struggles to provide its population.		
b. What percentage of the population suffers from malnourishment?		
c. What crops are grown in this country?		
d. Which foods are considered the staples in this country (rice, beans, cassava)?		
e. What are the reported causes of malnourishment in this country (environmental, economic, etc.)?		

continued on next page

STUDENT WORKSHEET

MALNUTRITION REPORT (CONTINUED)

Based on what you learned about the causes and effects of malnutrition in this country, what do you think can be done to help improve health here? In the chart below, identify three crops that could be nutritionally enhanced (by selective breeding or genetic engineering), grown, marketed, and distributed to the inhabitants of this country. *Confirm that the crop can grow in this country's climate and conditions.*

Nutrient-enhanced crop that could be grown in this country	Website Address/Citation

A challenge that farmers and scientists encounter after creating a nutrient-enhanced crop is whether other farmers will grow the food and people will incorporate it into their diet. Outline your plan to get one of the crops from your list into the country's cultivation system for widespread consumption. Create a five-step plan and explain each step.

Step	What you will do?	Why you will do it?
1		
2		
3		
4		
5		

MODULE 5 FOOD AND INGREDIENT EVALUATION

This module focuses on the evaluation process for new plant varieties developed for human or animal food. It also highlights new food labeling requirements.

The content in this module recommends that teachers will have already taught students the following underlying key concepts: methods used in food agriculture (e.g., selective breeding, genetic engineering) and reasons to use biotechnology (e.g., combat environmental pests, nutrient enhancement).

BACKGROUND INFORMATION: PART 1

New Variety Evaluation introduces how new plant varieties, including but not limited to varieties developed using modern methods of genetic modification, are evaluated for safe human and animal consumption. This content will inform the teacher, who can use all or part of the material to help students understand this process.

ACTIVITY

In the New Plant Variety Safety Evaluation Project activity, students will play the role of agricultural research scientists who are developing a new potato variety.

Time to Tune In

Secrets of Plant Genomes: Revealed! – Potatoes vs. Late Blight (7:41)
https:news.cals.wisc.edu/2011/05/23/potatoes-vs-late-blight/

Uganda's GMO Potato Story (3:11)
https://youtu.be/GUeXOWpYkGA

The Royal Society: What is Genetic Modification? (2:06)
https://www.youtube.com/watch?v=rx953M-tpp4

How are GMOs Made? The Genetically Modified Hawaiian Papaya Case Study (5:31)
https://www.youtube.com/watch?v=2G-yUuiqIZ0

BACKGROUND INFORMATION: PART 2

Food Labeling introduces new labeling requirements for some foods developed using biotechnology.

ACTIVITY

Are There Ingredients from GE Plants in My Food? uses a card sort that prompts students to examine the ingredients and labels of various foods, and then categorize which foods contain or don't contain ingredients that may come from GE plants.

Time to Tune In

Major science group weighs in on safety of genetically modified foods (2:40)
https://www.cbsnews.com/news/genetically-modified-foods-are-safe-to-eat-report-finds/

What does "organic" actually mean? (3:25)
https://grist.org/food/what-does-organic-actually-mean

BACKGROUND INFORMATION

PART 1
New Variety Evaluation

What makes up a banana?

INGREDIENTS: WATER (75%), **SUGARS (12%)** (GLUCOSE (48%), FRUCTOSE (40%), SUCROSE (2%), MALTOSE (<1%)), STARCH (5%), FIBRE E460 (3%), **AMINO ACIDS (<1%)** (GLUTAMIC ACID (19%), ASPARTIC ACID (16%), HISTIDINE (11%), LEUCINE (7%), LYSINE (5%), PHENYLALANINE (4%), ARGININE (4%), VALINE (4%), ALANINE (4%), SERINE (4%), GLYCINE (3%), THREONINE (3%), ISOLEUCINE (3%), PROLINE (3%), TRYPTOPHAN (1%), CYSTINE (1%), TYROSINE (1%), METHIONINE (1%)), **FATTY ACIDS (1%)** (PALMITIC ACID (30%), OMEGA-6 FATTY ACID: LINOLEIC ACID (14%), OMEGA-3 FATTY ACID: LINOLENIC ACID (8%), OLEIC ACID (7%), PALMITOLEIC ACID (3%), STEARIC ACID (2%), LAURIC ACID (1%), MYRISTIC ACID (1%), CAPRIC ACID (<1%)), ASH (<1%), PHYTOSTEROLS, E515, OXALIC ACID, E300, E306 (TOCOPHEROL), PHYLLOQUINONE, THIAMIN, **COLOURS** (YELLOW-ORANGE E101 (RIBOFLAVIN), YELLOW-BROWN E160a), **FLAVOURS** (3-METHYLBUT-1-YL ETHANOATE, 2-METHYLBUTYL ETHANOATE, 2-METHYLPROPAN-1-OL, 3-METHYLBUTYL-1-OL, 2-HYDROXY-3-METHYLETHYL BUTANOATE, 3-METHYLBUTANAL, ETHYL HEXANOATE, ETHYL BUTANOATE, PENTYL ACETATE), 1510, NATURAL RIPENING AGENT (ETHENE GAS).

Source: *Ingredients of an All-Natural Banana*, James Kennedy (VCE Chemistry teacher in Melbourne, Australia)

A typical diet for most people includes a variety of foods. Some of those foods are eaten in their original form (such as a whole apple or a banana), while other foods (such as apple pie or banana muffins) are a combination of ingredients. Food ingredients include spices, sweeteners, preservatives, and other substances that affect food characteristics such as taste, texture, and nutritional content. The ingredients in processed foods are required to be on the labels.

All foods, whether a whole food or a food ingredient, have a certain chemical identity, i.e., a characterizing composition that may include one or more of the following: amino acids, fatty acids, carbohydrates, vitamins, and minerals (to name a few). Some whole foods and ingredients may also have components that function as anti-nutrients (compounds that interfere with nutrient absorption) or natural toxins. Some components may also elicit allergenic responses in susceptible people. The levels of these food components provide the food's specific identity, i.e., what makes a banana a banana or a salmon a salmon, and what distinguishes corn oil from olive oil.

When a **new plant variety** is developed through genetic engineering (GE plant, GE variety), its composition is typically analyzed and compared with parental and commercial varieties. The levels of key components (nutrients, anti-nutrients, and toxins) are compared to assess any significant changes in those components. The safety and effects of any new or added substances are also assessed. Depending on the nature of the new substance(s) and with its history in other foods, the types of safety data will vary. The results of this comparison support whether or not food from the new variety has essentially the same safety profile and nutrient content as food from traditionally bred plants.

Accurate labeling helps people know more about the nutritional profile and ingredients in the food they eat. Consumers can use this information to ensure that they get enough of the nutrients they need and understand how to limit nutrients they want to minimize. They also can use food labels to identify and avoid food allergens such as peanuts, milk, wheat, and other ingredients that can cause allergic reactions in some people. If a food or ingredient is from a GE plant, it's the plant that has been genetically engineered, and not the ingredient per se. Many ingredients to date (like starches, sugars, and oils) derived from GE plants do not contain recombinant DNA, RNA, or protein and are chemically and functionally identical to their non-GE-derived counterparts. New labeling for some foods containing ingredients made through genetic engineering (bioengineering) becomes effective in 2020 with compliance mandated by 2022.

Safety Evaluation of Food from New Plant Varieties

The Federal Food, Drug, and Cosmetic Act requires that food from plants for humans and animals meet the same food safety requirements regardless of their origin, whether they are made from a plant variety that was created through crossbreeding, chemical or irradiation-induced mutagenesis, or genetic engineering. As new plant varieties were developed using GE tools over the past decades, FDA worked with the plant breeders to evaluate the safety of food from these GE varieties. This evaluation includes data analysis based on a comparison of food from the new GE plant variety to food from traditionally bred plant varieties with a history of safe use. Any differences identified during this comparison are then evaluated for safety.

BACKGROUND INFORMATION

Plant Biotechnology Consultation Program

FDA established a consultation process in the 1990s to work cooperatively with plant developers to help them ensure that foods made from new varieties, including those developed by genetic engineering, are safe and lawful. The consultation process allows a developer who intends to commercialize a new plant variety developed using modern genetic modification methods to meet with FDA to identify and discuss relevant safety, nutritional, or other regulatory issues about food for humans and animals made from the new variety. Plant breeders conduct tests and gather science-based evidence to verify that food from the new variety is as safe to eat as food from traditionally-bred varieties, and then submit the data and information to FDA for evaluation. FDA evaluates the submission and responds to the developer by letter. Since 1994, FDA has evaluated more than 180 new GE plant varieties through this program. For a list of completed consultations, see FDA's **Biotechnology Consultations database**.

Pre-market Consultation or Approval

Some food ingredients require FDA approval before marketing and some don't. A voluntary consultation process is one way for plant developers to check with FDA to see if food from the new plant variety contains a food additive that requires approval.

Safety Evaluation of GE Plants

Developers of GE plants gather information and conduct scientific studies to generate data, which they use to evaluate foods and ingredients from new varieties for safety and nutrition. Their review of food from the new varieties includes an examination of the following factors:

- **Identity**: Analyses to confirm the intended changes, including confirmation of the new or edited DNA, of new proteins produced from the DNA, and of other intended effects (traits).
- **Composition**: Whether key nutrients are within the expected ranges of values for the crop, whether endogenous (naturally occurring) toxins or antinutrients (compounds that interfere with the absorption of nutrients) are within acceptable levels
- **Safety and Regulatory Issues**: Potential for toxicity/allergenicity of new substances, and whether new substances require premarket review and approval by FDA by law. If the added substances are pesticides, they must be evaluated for food and environmental safety and authorized for use by the U.S. Environmental Protection Agency (EPA).

Identity

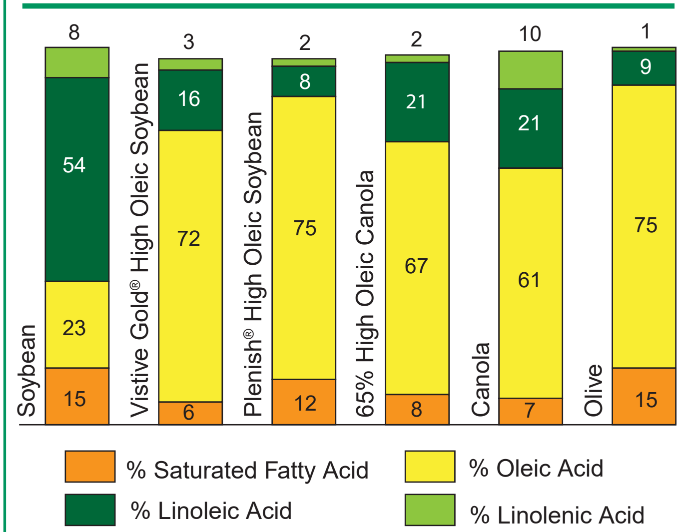
Developers of new plant varieties, including new GE varieties, collect data to identify distinguishing attributes of the new traits in the plant and assess whether any new proteins or components present in the new variety are safe for humans or animals to eat.

Developers of new GE varieties gather data to identify and assess attributes of food from the new variety. Their approach includes:

1. Recording detailed descriptions of the laboratory methods and results
2. Identifying the new, inserted, changed or edited DNA (this may include the use of DNA sequencing). This can include confirming that the intended genetic change occurred.
3. Identifying the new protein(s) created as a result of the genetic change (this may include the use of amino acid sequencing)
4. Measuring levels of new proteins or other substances produced in the plant and determining their levels in food (if present)

When a substance produced in a new GE plant variety is one that is already present at a comparable level in currently consumed foods, a safety question about the new substance is unlikely. For example, high oleic acid soybean oil has higher levels of oleic acid compared to typical soybean oils, but the higher levels are similar to other food oils, such as canola and olive oil.

Comparing Some Oils



Inform Magazine: High-oleic soybeans get the global green light, chart http://www.informmagazine-digital.org/informmagazine/april_2018/MobilePagedArticle.action?articleId=1367747#articleId1367747

When a substance produced in a new GE variety is one that is not present – or is present only at lower levels – in currently consumed foods, its safety in food must be evaluated.

BACKGROUND INFORMATION

Composition

Developers of new plant varieties, including new GE varieties, collect data on the composition of the new variety by conducting field trials. Field trials for new GE varieties frequently include the new GE variety (test), along with a genetically comparable plant variety as a control and possibly one or more commercial varieties as reference varieties. Samples from the edible parts of the test, control, and reference varieties are collected, and the levels of key nutrients, anti-nutrients, and toxins are measured.

The results of the compositional analysis for the new GE variety are then compared with the results for the control and reference varieties. They may also be compared with plant composition data in science journals and public databases.

Safety and Regulatory Issues

Health and Safety

New substances present in food from the new plant varieties, such as those introduced by genetic engineering, are studied to determine whether they could be toxic or allergenic. One way to determine if a new protein from the GE plant has the potential to be toxic or allergenic is to compare its amino acid sequence for similarity to those of known toxins and allergens. Another way is to consider whether the source of the DNA encoding the new protein is toxigenic or allergenic. The safety of substances that are not proteins can be evaluated, for example, through:

- scientific principles, such as whether the substance has historically been safely consumed in the diet and the similarity of the substance to other substances safely consumed in the diet
- dietary exposure estimate
- knowledge of their digestive fate once consumed
- data from toxicity studies of the substance

The composition of food from new plant varieties is also evaluated for meaningful changes in their nutritional values or increased levels of endogenous anti-nutrients or toxins. Plants are an important source of nutrients in the diet, so changes in their composition have the potential to impact the health of humans and animals. Some plants that we eat also produce natural toxins that are usually defense molecules against environmental threats such as bacteria, fungi, insects, or predators. Two examples of natural toxins are glycoalkaloids in potatoes and psoralens in celery. These natural toxins are generally not present in domesticated food crops at levels high enough to affect human or animal health, but breeding may lead to changes in the levels of these substances.

Compositional changes are evaluated by dietary experts for their potential to impact the health of humans or animals. In some cases, the compositional change is specifically made to improve dietary intake status. For example, Golden Rice was developed to address vitamin A deficiency in south and southeast Asian countries where people typically consume a rice-based diet. However, if the level of a nutrient in the new plant variety is found to be too low or too high, this could lead to dietary deficiency or excess, respectively. Likewise, if the level of an anti-nutrient or toxin is found to be too high, this could cause harm. Either way, it is important to conduct the analysis in the context of the total diet. Scientists consider the role of food from the plant in the diet of humans and animals when performing this analysis. For example, they consider whether the food is an important source of particular vitamins and minerals in the context of the total diet.

Long-Term Safety

Scientists with expertise assessing the long-term safety of food and food ingredients for humans and animals consider several factors when they evaluate food from new plant varieties, including new GE varieties. This includes information about the long-term safety of the food from traditionally bred crops and information about the food safety of the newly introduced traits. The plant's components (fiber, protein, fat, DNA, anti-nutrients, etc.) have typically been part of the human diet for thousands of years. Just like the plant's endogenous nucleic acids and proteins, the recombinant nucleic acids and proteins are degraded during digestion in the human or animal gastrointestinal tract into their building blocks. For all GE plant varieties evaluated to date through FDA's Plant Biotechnology Consultation Program, the long-term safety of food from the new GE variety is expected to be the same as that of food from comparable traditionally-bred and safely-consumed plant varieties.

Note: When FDA considers the safety of foods from a new plant variety, it considers uses of the plant in food for both humans and animals.

BACKGROUND INFORMATION

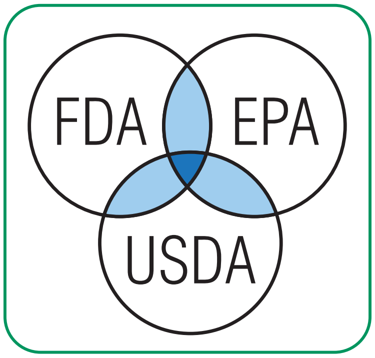
Developer's Assessment

Developers of new plant varieties evaluate safety, nutritional, and other regulatory issues. The developers may choose to submit a summary to FDA describing their approach. For new GE varieties, the summary usually includes:

1. The name of the food and the crop from which it is derived
2. A description of how the food will be used, including animal food uses
3. The sources, identities, and functions of introduced genetic material
4. The purpose or intended technical effect of the modification, and its expected effect (if any) on the composition or characteristic properties of the human or animal food
5. The identity and function of expression products (new proteins or RNA) encoded by the introduced genetic material, including an estimate of the concentration of any expression product in the new GE variety or derived food
6. The basis for concluding that foods containing the expression products can be safely consumed, including information showing the expression products are not toxins or allergens
7. A comparison of the composition of food from the new variety with that of food from the original parental variety or other commonly consumed varieties, particularly nutrients and toxins that occur naturally in the food
8. A discussion of available information addressing whether the potential for food from the new variety to induce an allergic response has been altered by the genetic modification
9. Any other information relevant to the safety and nutritional assessment of the food from the new GE variety.

A team of FDA scientists with expertise in food safety and nutrition for humans and animals reviews the developer's data, and asks the developer to clarify or answer questions about their data. FDA reviews the developer's responses and continues asking questions until no further questions remain. FDA prepares an evaluation summary and sends the developer a letter stating the agency did not identify any safety or regulatory issues requiring further evaluation and reminding them that they remain legally obligated to ensure the safety of the final products they bring to market. For more Information, see FDA's Fact Sheet:
New Plant Variety Regulatory Information
https://www.fda.gov/food/food-new-plant-varieties/new-plant-variety-regulatory-information

Coordinated Biotechnology Regulation



Three federal agencies (FDA, USDA, and EPA) act under a coordinated regulatory framework to ensure the overall safety of GE new plant varieties:

- FDA regulates the safety of all food products for humans and animals in the United States other than meat, poultry, catfish and certain egg products, which are regulated by USDA.
- USDA, specifically the Animal and Plant Health Inspection Service (APHIS), is responsible for protecting agriculture from pests and diseases. They supervise field testing and monitor GE seed distribution until the GE plant variety is shown not to be harmful to agriculture and the environment.
- EPA regulates pesticides, including those that are produced in plants as a result of genetic engineering. To protect human and animal health, EPA assures that pesticidal substances expressed in GE plants are safe for consumption. EPA also regulates the environmental safety of the pesticidal substances.

To learn more about each agency's role, explore the resources below.

- Coordinated Framework: **https://usbiotechnologyregulation.mrp.usda.gov/biotechnologygov/home**
- FDA: *Food from New Plant Varieties* **www.fda.gov/Geplantfoods**
- USDA: *Regulation of Biotechnology* **https://www.aphis.usda.gov/aphis/ourfocus/biotechnology**
- EPA: *EPA's Regulation of Biotechnology for Use in Pest Management* **https://www.epa.gov/regulation-biotechnology-under-tsca-and-fifra/epas-regulation-biotechnology-use-pest-management**

GE Animals

GE animals can be developed for a variety of purposes including disease-resistance, improved nutritional composition (e.g. healthier fat or lower allergenicity), and greater productivity (faster growth with less feed). For example, AquAdvantage Salmon was genetically altered to grow more quickly, using a gene commonly found in another type of fish. This salmon is the first GE animal to be approved for human consumption.

BACKGROUND INFORMATION

Scientific Perspectives

The scientific consensus is that food from GE plant varieties available for consumers is safe, e.g., poses no greater health risks or environmental concerns than their non-GE counterparts.

Some of the scientific organizations that support this position are:

- FDA, USDA, and EPA
- National Research Council
- American Association for the Advancement of Science
- Council on Science and Public Health
- World Health Organization
- European Food Safety Authority

Evolving Science

More technologies emerge as farmers and scientists address changing needs in food agriculture. One approach, genome editing, describes a relatively new set of techniques to make changes at specific locations in the DNA of a plant, animal, or other living organism. (See Module 2.) These technologies can be used to introduce, remove, or substitute one or more specific nucleotides at a specific site in the organism's genome. Examples of different genome editing techniques include clustered regularly interspaced short palindromic repeat associated nucleases (CRISPR), zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and oligonucleotide-directed mutagenesis (ODM). FDA completed its first voluntary food safety consultation on food derived from a plant produced using genome editing in February 2019. Regardless of how a plant is produced, food from the plant must be safe.

Examples of Foods Made with GE Techniques

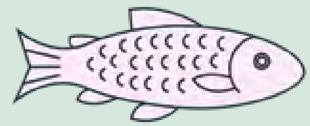
Plant

- USDA Approves Genetically Modified Non-Browning Apple (Arctic® Apples) **www.youtube.com/watch?v=3LFmWhJu6Pw**

AquAdvantage Salmon

- AquAdvantage Salmon is the first GE animal for consumption with an FDA-approved application. The company collected data for over 10 generations of the animal.

Read the FDA AquAdvantage Salmon Fact Sheet: **https://www.fda.gov/animal-veterinary/animals-intentional-genomic-alterations/aquadvantage-salmon-fact-sheet**



Federal agency inventories of safety evaluations

(search by product, e.g., apple):

- FDA: **https://www.fda.gov/food/consultation-programs-food-new-plant-varieties/final-biotechnology-consultations**
- USDA: **https://www.aphis.usda.gov/aphis/ourfocus/biotechnology/regulatory-processes/permits/status-update/release-permits**
- EPA: **https://www.epa.gov/ingredients-used-pesticide-products/current-and-previously-registered-section-3-plant-incorporated**

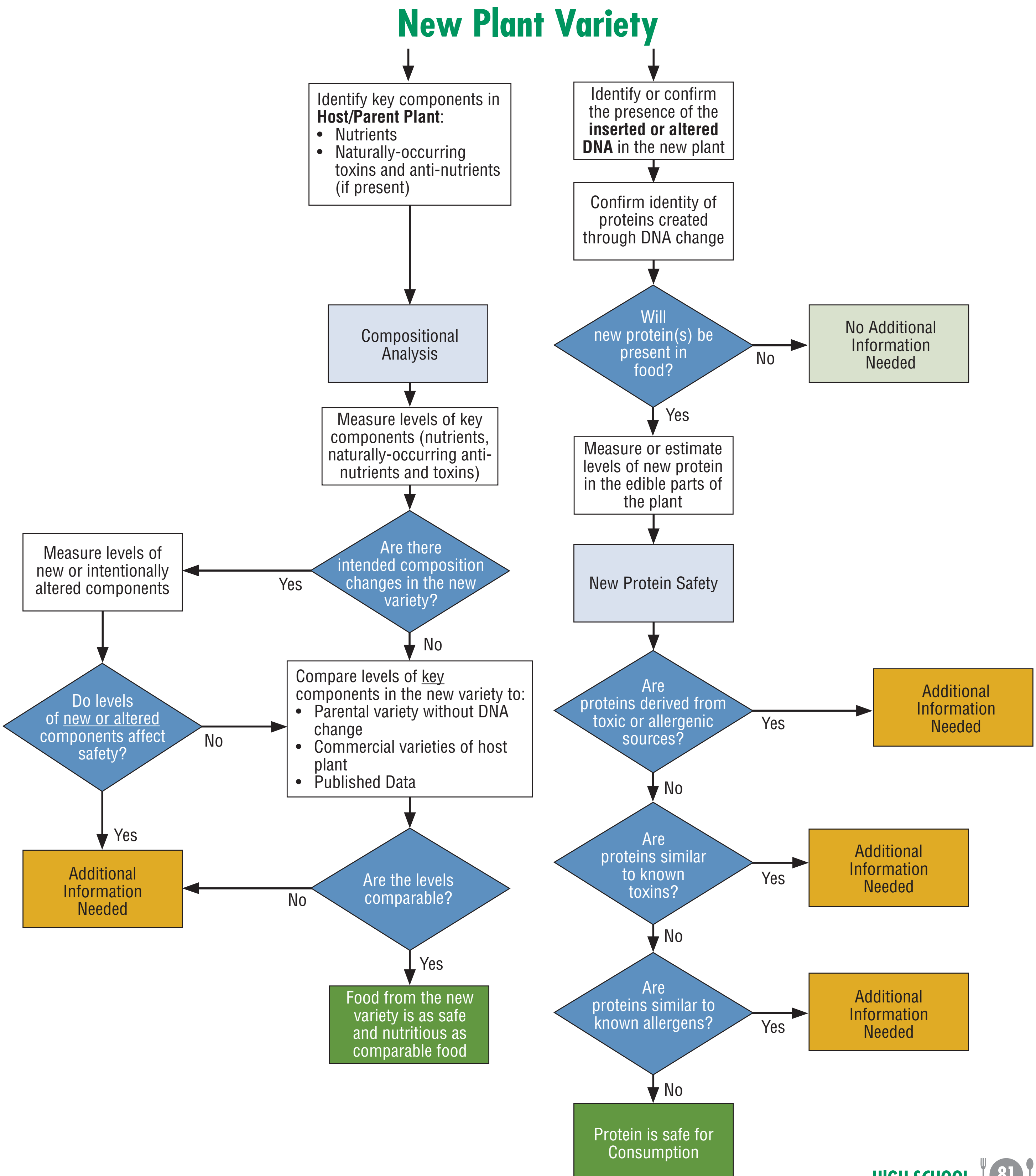
DID YOU KNOW?

FDA and USDA use different words to characterize the regulatory processes by which a GE plant is evaluated and designated as safe. FDA uses a consultation process to evaluate whether food from a GE plant requires FDA's premarket approval for safe use. USDA uses a petition process to deregulate (remove from USDA's regulatory oversight) GE plants once it is determined they do not pose a plant pest risk.

Three-Part, Science-Based Approach to Safety Evaluation of New Plant Varieties

Case-by-case approach	Comparative approach	Focus on new substances
Does the plant have a history of safe use? Is it typically used in human food? In animal food? What parts of the plant are eaten? Is it eaten fresh or is it processed?	Are the levels of important nutrients in food from the plant similar to the levels in food from varieties of the plant with a history of safe use? Are the levels of toxins and anti-nutrients the same or lower? If the levels are different, do the differences affect safety or nutrition?	Are there new substances in the plant? Will the new substances be present in food made from the new plant? If so, are the new substances toxins, antinutrients, or allergens?

SAFETY EVALUATION PROCESS FOR NEW PLANT VARIETIES



ACTIVITY 1: NEW PLANT VARIETY SAFETY EVALUATION PROJECT

TIME Two 45-Minute Class Periods

ACTIVITY AT A GLANCE

Students will explore data collection for a hypothetical new potato variety to be evaluated for safety. They will also use a flow chart to evaluate whether the new variety is as safe and nutritious as comparable food or if additional information is needed to make a decision.

TIME TO TUNE IN

Secrets of Plant Genomes: Revealed! – Potatoes vs. Late Blight (7:41)
https://news.cals.wisc.edu/2011/05/23/potatoes-vs-late-blight/

Uganda's GMO Potato Story (3:11)
https://youtu.be/GUeXOWpYkGA

The Royal Society: What is Genetic Modification? (2:06)
https://www.youtube.com/watch?v=rx953M-tpp4

How are GMOs Made? The Genetically Modified Hawaiian Papaya Case Study (5:31)
https://www.youtube.com/watch?v=2G-yUuiqIZ0

GETTING STARTED

MATERIALS

- Copies of the **Safety Evaluation Process for New Plant Varieties** flow chart on page 81
- Copies of the **New Plant Variety Safety Evaluation** worksheet
- For specific examples of data listings in FDA biotechnology consultation summaries, using potato examples, see BNF numbers 152, 153, 146, 141, 130 at this *Consultations on Food from New Plant Varieties* site: **https://www.accessdata.fda.gov/scripts/fdcc/?set=Biocon**
- Copies of FDA's Fact Sheet: **New Plant Variety Regulatory Information**, which can be downloaded from the following website: **https://www.fda.gov/food/food-new-plant-varieties/new-plant-variety-regulatory-information** (printed or online)
- Personal devices or computers with internet access

ADVANCE PREPARATION

- Divide the class into small groups of 2 - 3 students.
- Make copies of the **Safety Evaluation Process for New Plant Varieties** flow chart (page 81) for each group.
- Make copies of the **New Plant Variety Safety Evaluation** worksheet for each student.
- Make copies of **New Plant Variety Regulatory Information** for each group. **https://www.fda.gov/food/food-new-plant-varieties/new-plant-variety-regulatory-information** (or ensure online access)

NEW PLANT VARIETY SAFETY EVALUATION PROJECT

INTRODUCTION

This activity focuses on identifying characteristics of a new potato variety and using data to evaluate its safety. Potato traits that might be altered include: reduced susceptibility to bruising, non-browning, blight resistance, insect resistance, or lower asparagine content (a variable in acrylamide production levels when cooked).

Engage students by asking:

- *Whose responsibility is it to collect data on a new plant variety?*
- *What types of data are needed to evaluate whether a new variety is safe?*
- *What else might you need to document?*
- *What type of trait would you like to alter?*

STUDENT PROCEDURE

Day 1

1. Watch these two videos, and then review the first part of the **New Plant Variety Safety Evaluation Project** worksheet that discusses potato varieties.

   Secrets of Plant Genomes: Revealed! – Potatoes vs. Late Blight (7:41)
   https:news.cals.wisc.edu/2011/05/23/potatoes-vs-late-blight/

   Uganda's GMO Potato Story (3:11)
   https://youtu.be/GUeXOWpYkGA

2. Now consider the process of developing and evaluating a new potato trait as you watch the next two videos:

   The Royal Society: What is Genetic Modification? (2:06)
   https://www.youtube.com/watch?v=rx953M-tpp4

   How are GMOs Made? The Genetically Modified Hawaiian Papaya Case Study (5:31)
   https://www.youtube.com/watch?v=2G-yUuiqIZ0

3. Refer to your worksheet and choose a potato trait to alter.

4. Read **New Plant Variety Regulatory Information** and highlight the important points that should be considered for a new plant variety. **https://www.fda.gov/food/food-new-plant-varieties/new-plant-variety-regulatory-information**

Day 2

1. Complete the **New Plant Variety Safety Evaluation Project** worksheet using Internet resources and the **Credible Source Guide**.

2. Use the **Safety Evaluation Process for New Plant Varieties** flow chart to determine whether your new variety would be as safe and nutritious as comparable food or if additional information would be needed to decide.

REVIEW

Whose role is it to collect safety evaluation data? The plant developer or breeder must keep detailed records and collect DNA and protein sequence data for safety evaluation. The developers and FDA reviewers examine and evaluate this data as part of the safety evaluation process.

What are some key characteristics of a new GE plant variety that must be evaluated for safety? New GE varieties must be evaluated for potential toxicity, allergenicity, and nutritional values.

NEW PLANT VARIETY SAFETY EVALUATION PROJECT

EXTENSIONS

Students could do one or more of the following activities:

1. Prepare a draft summary evaluation report on a hypothetical new GE plant variety.
2. Brainstorm possible recommendations for a different process.

SUMMARY

During the research and development of new plant varieties, including varieties developed by modern methods of genetic modification, scientists collect, share, and evaluate data to assess the safety of food derived from the new varieties. FDA and non-FDA scientists both have critical roles in this process.

ADVANCED EXTENSION

For an advanced activity, students could research Golden Rice, which has two new proteins (one from corn and one from bacteria), and an increase in beta-carotene. They could calculate exposure in food and determine if the exposure is safe or unsafe.

The following resources provide background information, including protein concentration data and values available for rice consumption in the United States and other countries.

- Background video: *Golden Rice – fighting Vitamin A deficiency in the Philippines and Bangladesh* (2:41) https://www.youtube.com/watch?v=5ts9NLOUJuM
- *Consultation Programs on Food from New Plant Varieties* https://www.fda.gov/food/food-new-plant-varieties/consultation-programs-food-new-plant-varieties
- *International Rice Outlook 2014 – 2024* https://ageconsearch.umn.edu/record/199846/files/AGRM%20International%20Rice%20Outlook%20Baseline%20Projections%202014-2024%20SP%2001%202015.pdf

UP NEXT

Now that you've explored the safety evaluation process of new GE plant varieties, let's look at how products with ingredients from GE plants or animals might be labeled.

RESOURCES

- *Commercial Potato Production in North America – The Potato Association of America Handbook* (numerous potato varieties on pages 28 -31) https://potatoassociation.org/wp-content/uploads/2014/04/A_ProductionHandbook_Final_000.pdf
- *New Plant Variety Regulatory Information* https://www.fda.gov/food/food-new-plant-varieties/new-plant-variety-regulatory-information
- *GM Plants Questions and Answers: The Royal Society* https://royalsociety.org/-/media/policy/projects/gm-plants/gm-plant-q-and-a.pdf
- *USDA: Biotechnology FAQs* www.usda.gov/topics/biotechnology/biotechnology-frequently-asked-questions-faqs
- *Understanding New Plant Varieties* https://www.fda.gov/food/food-new-plant-varieties/understanding-new-plant-varieties
- *Genetically Engineered Crops (The National Academies)* The PDF version of the book can be downloaded for free from this web page. www.nap.edu/catalog/23395/genetically-engineered-crops-experiences-and-prospects
- *The Case for Engineering Our Food* https://www.youtube.com/watch?v=wZ2TF8-PGQ4
- *How to Make a Genetically Modified Plant* www.youtube.com/watch?v=JtkhHIG3nx4 (review)
- *Organisation for Economic Co-operation and Development, plant composition homepage* www.oecd.org/chemicalsafety/biotrack/consensus-document-for-work-on-safety-novel-and-foods-feeds-plants.htm

STUDENT WORKSHEET

NEW PLANT VARIETY SAFETY EVALUATION PROCESS

Name ______________________________ Date ____________ Class/Hour __________

There are dozens of potato varieties that are grown in the United States. Your research team will genetically engineer a new potato variety from a host plant, the Yukon Gold potato.

Your project is to alter a trait that reduces susceptibility to one of the following three conditions:

☐ bruising ☐ blight ☐ insect damage (Choose one)

You are making a genetically engineered new variety. Decide how you want to alter the DNA.

Will you ☐ insert a transgene (a gene from another organism) or use ☐ genome editing?

Research your "host" potato variety using the internet (refer to the Credible Source Guide). First, look at Organisation for Economic Cooperation and Development) Potato composition document (pages 15 - 21) **https://www.oecd.org/env/ehs/biotrack/46815167.pdf**. The National Agricultural Library has many good sources, including FoodData Central **https://fdc.nal.usda.gov/**. Search for a specific potato, e.g., Yukon Gold, or you will get too much information. Complete the table below and record your sources.

Use the Safety Evaluation Process flow chart as a guide to determine if your new potato variety is "as safe and nutritious as comparable food" or if "additional information is needed." Your variety is hypothetical, so you have not actually tested its final composition in a laboratory. As you consider the flow chart questions (blue diamonds), you might not have enough information about your new variety to answer "yes" or "no." Choose a hypothetical answer to describe your variety, and circle the "yes" or "no" answer.

Potato Composition (% fresh weight, %FW)	A. Host Plant (Yukon Gold Potato)	B. New DNA (inserted or altered)	C. New Potato Variety	Credible Sources for A. and B. Data
Nutrient composition (starch, protein, fat, Vitamin C, potassium, etc.)				
Naturally-occurring toxins				
Naturally-occurring anti-nutrients				
Naturally-occurring allergen(s), if any				

Would you expect amino acids or proteins created through the change in DNA be present in the new potato? ____________

Is your new potato variety... ☐ "as safe and nutritious as comparable food" or ☐ "additional information is needed" (select one).

Explain your decision. ____

____

BACKGROUND INFORMATION

PART 2
Food Labeling

The information listed on food labels serves different purposes. Some labeling is for safety and identity, and other labeling is for consumer interest/marketing (e.g., USDA's National Organic Program). Some information is required by law, and some is voluntary.

FDA and Labeling of Food From GE Plants

FDA's mandatory labeling requirements that apply to food, including from GE plants, are the same requirements that apply to all other foods under FDA's authority. The law requires foods to be identified on their label by their common and usual name. The common and usual name of a food is a name that appropriately describes the basic nature of the food or its characterizing properties or ingredients. The composition and functional properties of many ingredients made from GE plants are comparable to non-GE-derived counterparts, so the GE plant-derived ingredients are often identified by the same common or usual name. However, in cases where the composition has been changed in a meaningful way, then food from the new plant variety, GE or non-GE, would have a new name that describes the change (e.g., high oleic acid soybean oil, pink pineapple).

Mandatory Labeling of "Bioengineered (BE)" Food

In July 2016, Congress passed the National Bioengineered Food Disclosure Law, which directed USDA to establish standards for disclosing human foods that are or have ingredients that are bioengineered (BE). In December 2018, after gathering information and deliberating on what the standards should require, USDA announced the National Bioengineered Food Disclosure Standard (NBFDS or "the Standard"), which defines BE foods as those that contain detectable genetic material that has been modified through certain laboratory techniques and cannot be created through conventional breeding or found in nature. The Standard requires food manufacturers, importers, and certain retailers to disclose information about whether food offered for retail sale is BE or uses BE food ingredients. NBFDS is a marketing standard designed to provide consumers more information about their food. It does not address the health and safety of bioengineered foods, including any nutritional aspects of such foods.

The Standard requires food manufacturers, importers, and certain retailers to ensure that BE foods, and foods with BE ingredients, include a BE food disclosure. The disclosure may be made using one of several options: text, symbol, electronic or digital link, and/or text message. These disclosures are required by January 1, 2022.

Because the Standard defines BE foods as those that contain detectable modified genetic material, many highly refined foods will not require a BE food disclosure. Many highly refined foods are processed in a way that makes modified genetic material undetectable, which means these foods and ingredients are no longer considered BE foods. For example, sugar that is made from a BE sugar beet is usually processed to the point that modified genetic material is not detectable. As a result, sugar from a BE sugar beet would likely not require a BE food disclosure. However, the food manufacturer could voluntarily use the "Derived from bioengineering" disclosure shown below.

NOTE: Foods from genome edited plants usually do not require BE labeling, dependent on whether they fall within the definition of bioengineered foods as established in the Standard.

BE Labels

For more information on USDA's BE Standard and labeling, see www.ams.usda.gov/rules-regulations/be.

USDA's National Organic Program

What are USDA "certified organic" foods? USDA certified organic foods are grown and processed according to federal guidelines addressing, among many factors, soil quality, animal raising practices, pest and weed control, and use of additives. A product cannot be labeled "organic" unless it meets the criteria set forth by the National Organic Program (NOP), overseen by USDA's Agricultural Marketing Service, for organic food. According to the NOP criteria, the use of genetic engineering is prohibited.

The NOP is a marketing standard and not a safety standard. That is, the NOP is a standard required for labeling a product as USDA certified organic and does not imply that a food is more or less safe than its non-organic counterparts. In fact, USDA certified organic foods and non-organic foods must meet the same food safety standards.

For more information, see https://www.ams.usda.gov/rules-regulations/organic/labeling.

ACTIVITY 2: ARE THERE INGREDIENTS FROM GE PLANTS IN MY FOOD?

TIME Two 45-Minute Class Periods

ACTIVITY AT A GLANCE

In this activity, students will examine a variety of foods and their ingredients to try to determine which foods contain ingredients that may come from GE plants.

TIME TO TUNE IN

Major science group weighs in on safety of genetically modified foods (2:40)
https://www.cbsnews.com/news/genetically-modified-foods-are-safe-to-eat-report-finds/

What does "organic" actually mean? (3:25)
https://grist.org/food/what-does-organic-actually-mean

GETTING STARTED

MATERIALS

- **Food Labels Card** set
- Avery Mailing Labels #8163
- 3 x 5 Index Cards
- **Are There Ingredients from GE Plants in My Food?** worksheet
- Copies of USDA's fact sheet for consumers: **What is a Bioengineered Food?** https://www.ams.usda.gov/sites/default/files/media/BE_Consumer.pdf
- Personal devices or computers with internet access

ADVANCE PREPARATION

- Divide the students into groups of 3 - 5.
- Create the **Food Labels Card** set for each group of students by copying them (pages xx – xx) on Avery Mailing Labels #8163; then attach the labels to 3 x 5 Index Cards. For longer lasting card sets, laminate the cards. The cards could also be made by copying the templates on card stock and cutting them apart. Making sets in different colors helps keep the sets together.)
- Make a copy of the **Are There Ingredients from GE Plants in My Food?** worksheet for each group.
- Make copies for each student of the USDA fact sheet for consumers: **What is a Bioengineered Food?** https://www.ams.usda.gov/sites/default/files/media/BE_Consumer.pdf
- Distribute a **Food Labels Card** set to each group.

ARE THERE INGREDIENTS FROM GE PLANTS IN MY FOOD?

INTRODUCTION

Explain that a variety of labeling approaches are used to identify products that do or do not include ingredients from GE plants, and that different terms, such as genetically engineered, bioengineered, and GMO, are also used.

Discuss a few examples of potential ingredients from GE plants in food.

- corn starch could come from GE corn
- soybean oil could come from GE soybeans
- canola oil could come from GE canola
- soy lecithin could come from GE soybeans

Ask students to brainstorm about the kinds of information they find on food labels. Groups should share their ideas with the whole class.

Note: If students need a refresher on the Nutrition Facts label, refer to these resources:

- **What's on the Nutrition Facts Label** www.accessdata.fda.gov/scripts/InteractiveNutritionFactsLabel/factsheets/Whats_On_The_Nutrition_Facts_Label.pdf
- **Interactive Nutrition Facts Label** www.accessdata.fda.gov/scripts/InteractiveNutritionFactsLabel/#intro

STUDENT PROCEDURE

1. Watch the videos:

   Major science group weighs in on safety of genetically modified foods (2:40)
   www.cbsnews.com/news/genetically-modified-foods-are-safe-to-eat-report-finds

   What does "organic" actually mean? (3:25)
   https://grist.org/food/what-does-organic-actually-mean
2. Each group should have a **Food Labels Card** set that will be divided into two groups based on the ingredients:

   (a) Foods with ingredients that could come from GE plants

   (b) Foods with ingredients that have no counterpart from a GE plant

   Discuss the food (and any ingredients) shown on each card, and decide which of the two categories is appropriate for that item.
3. Record the items in each category in the data table.
4. As a class, review the foods you placed in each category and explain your reasons for placement. Modify your data tables, as needed, during the discussion.
5. Discuss whether there are any food safety concerns about eating foods with GE ingredients. Support your reasons with facts.

REVIEW

Labeling is used to inform consumers as well as for marketing, cultural, and other purposes. One example of marketing is when foods are labeled "non-GMO" even though there are no GE counterparts (e.g., salt). Based on what you have learned in this activity, would you label these foods non-GMO? Why or why not?

ARE THERE INGREDIENTS FROM GE PLANTS IN MY FOOD?

EXTENSIONS

Students could do one or more of the following activities:

1. Relate this activity to the ✓(Check) Your Snacks! activity (p. 56) from ***Science and Your Food Supply: Using the Nutrition Facts Label to Make Healthy Food Choices*** **https://www.fda.gov/media/109430/download** Students could check the labels on their favorite snacks to see if any of them have ingredients from GE plants.
2. Bring in food containers from home and discuss the variety of information and labeling on package containers. Discuss which information is: (1) required or voluntary and (2) used for health/nutrition or marketing/cultural reasons.

RESOURCES

- *Biotechnology Consultations on Food from GE Plant Varieties*
  https://www.cfsanappsexternal.fda.gov/scripts/fdcc/index.cfm?set=NewPlantVarietyConsultations
- *FDA's Interactive Food Label*
  www.accessdata.fda.gov/scripts/InteractiveNutritionFactsLabel/#intro
- *Types of Food Ingredients*
  www.fda.gov/food/food-additives-and-gras-ingredients-information-consumers/types-food-ingredients
- *FDA – Labeling and Nutrition*
  www.fda.gov/food/labelingnutrition/default.htm
- *FDA Regulatory Requirements for Nutrient Content Claims*
  www.ncbi.nlm.nih.gov/books/NBK209851
- *What's New With the Nutrition Facts Label*
  https://www.fda.gov/food/new-nutrition-facts-label/whats-new-nutrition-facts-label
- *USDA: List of Bioengineered Foods*
  www.ams.usda.gov/rules-regulations/be/bioengineered-foods-list
- *Major science group weighs in on safety of genetically modified foods*
  www.cbsnews.com/news/genetically-modified-foods-are-safe-to-eat-report-finds
- *Science and Our Food Supply: Using the Nutrition Facts Label to Make Healthy Food Choices*
  www.fda.gov/downloads/Food/FoodScienceResearch/ToolsMaterials/UCM586423.pdf
- *Animals with Intentional Genomic Alterations (FDA)*
  https://www.fda.gov/animal-veterinary/biotechnology-products-cvm-animals-and-animal-food/animals-intentional-genomic-alterations

STUDENT WORKSHEET
ARE THERE INGREDIENTS FROM GE PLANTS IN MY FOOD?

Name ______________________________ Date ____________ Class/Hour __________

Look at each **Food Label** card and think about the ingredients in that item. If there isn't a label, research the food or beverage to find out what ingredients it might contain. After you have determined which group the food belongs to (GE/possible GE or Non-GE), put a check mark in that box below and list the reason(s) for that choice.

Food Card item	Marketing label, e.g., organic	Food or ingredients that may come from GE crops	GE or Possibly GE	Food or ingredients with no corresponding GE counterpart	Non-GE
Arctic Apple					
Cinnamon Crunch Cereal					
Clementines					
Coffee					
Cosmic Crisp Apple					
Cottage Cheese					
Cream Filled Cookies					
Cut Green Beans					
Graham Crackers					
Granola Bars					
Honey Nut Oat Cereal					
Margarine					
Orange Juice					
Pita Bread					
Rainbow Papaya					
Seedless Watermelon					
Sour Cream					
Table Salt					
Tea					
Wheat Bread					

HONEY NUT OAT CEREAL

INGREDIENTS:
(Whole Grain Oats, Sugar, Oat Bran, Modified Corn Starch, Honey, Brown Sugar Syrup, Salt, Ground Almonds, Calcium Carbonate, Trisodium Phosphate, Wheat Flour, Vitamin E, Zinc, Iron, Vitamin C, Niacinamide, Vitamin B6, Vitamin B2, Vitamin B1, Vitamin A Palmitate, Folic Acid, Vitamin B12, Vitamin D)

CREAM FILLED COOKIES

INGREDIENTS:
Sugar, Unbleached Enriched Flour (Wheat Flour, Niacin, Reduced Iron, Thiamine Mononitrate {Vitamin B1}, Riboflavin {Vitamin B2}, Folic Acid), Palm, And/Or Canola Oil, High Fructose Corn Syrup, Cornstarch, Salt, Baking Soda, Soy Lecithin, Naturally And Artificial Flavor

COSMIC CRISP APPLE

ARCTIC APPLE

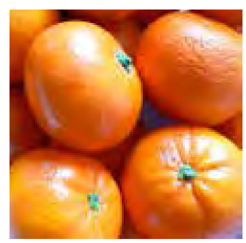
SEEDLESS WATERMELON

RAINBOW PAPAYA

GRANOLA BARS

INGREDIENTS:
Rolled Oats, Brown Sugar, Rice Flour, Rolled Wheat, Soybean Oil, Whole Wheat Flour, Soy Protein, Dried Coconut

CLEMENTINES



CINNAMON CRUNCH CEREAL

INGREDIENTS:
Whole Grain Wheat, Sugar, Rice Flour, Canola Oil, Fructose, Maltodextrin, Dextrose, Salt, Cinnamon, Trisodium Phosphate, Soy Lecithin, Caramel Color. BHT Added to Preserve Freshness.

GRAHAM CRACKERS

INGREDIENTS:
Unbleached Enriched Flour (Wheat Flour, Niacin, Reduced Iron, Thiamine Mononitrate {Vitamin B1}, Riboflavin {Vitamin B2}, Folic Acid), Graham Flour (Whole Grain Wheat Flour), Sugar, Soybean and/or Canola Oil, Honey, Leavening (Baking Soda and/or Calcium Phosphate), Salt, Soy Lecithin, Artificial Flavor.

TABLE SALT

INGREDIENTS:
Salt, Calcium Silicate (an anticaking agent), Dextrose, Potassium Iodine

CUT GREEN BEANS

INGREDIENTS:
Organic Green Beans, Water, Sea Salt

PITA BREAD

INGREDIENTS:
Unbleached Enriched Flour (Wheat Flour Niacin Iron Thiamin Mono-Nitrate Riboflavin Folic Acid) Water Yeast Salt Dough Conditioners (Wheat Flour Mono-Diglycerides Calcium Sulfate Corn Starch Guar Gum Calcium Carbonate Soy Oil Salt Ascorbic Acid Ada Ammonium Sulfate Enzymes Sodium Meta Bisulfate Potassium Iodate) Preservatives Less Than 1% Calcium Propionate Potassium Sorbate.

WHEAT BREAD

INGREDIENTS:
Whole Wheat Flour, Water, Sugar, Wheat Gluten, Raisin Juice Concentrate, Wheat, Bran, Yeast, Molasses, Soybean Oil, Salt, Preservatives (Calcium Propionate, Sorbic Acid), Monoglycerides, DATEM, Calcium Sulfate, Grain Vinegar, Soy Lecithin, Soy, Whey (Milk)

COFFEE

INGREDIENTS:
Ground Coffee Beans

MARGARINE

INGREDIENTS:
Oil Blend (Canola, Palm, Fish, Flaxseed, And Olive Oils), Water, Contains Less Than 2% Of, Salt, Pea Protein, Natural And Artificial Flavors, Sunflower Lecithin, Vitamin A Palmitate, Beta-Carotene (Color), Vitamin D, Monoglycerides Of Vegetable Fatty Acids (Emulsifier); And Potassium Sorbate, Lactic Acid, TBHQ, Calcium Disodium EDTA (To Protect Freshness).

ORANGE JUICE

INGREDIENTS:
Water, Concentrated Orange Juice

COTTAGE CHEESE

INGREDIENTS:
Organic Cultured Pasteurized Skim Milk, Organic Pasteurized Cream, Organic Nonfat Milk, Salt, Citric Acid, Organic Guar Gum, Organic Locust Bean Gum, Acidophilus and Bifidus Cultures.

SOUR CREAM

INGREDIENTS:
Cultured Pasteurized Cream and Fat Free Milk, Enzymes

TEA

INGREDIENTS:
Green Tea

CAPSTONE PROJECTS (OPTIONAL EVALUATION)

We hope that this supplementary curriculum *Science and Our Food Supply: Exploring Food Agriculture and Biotechnology* has helped to increase understanding of a broad range of related topics. The activities in each module were designed to assess students' understanding of content highlighted in that module. In some cases, the activities also required consideration and application of concepts learned in a previous module. The optional Extension activities provided opportunities to explore module content from a different perspective.

As a final assessment, students could select one of the following options:

1. What was something you learned from this curriculum that surprised you? Write a paper or design an education initiative to describe this concept to friends, family, and your community.

2. Which topic was hardest for you to understand? Write a paper or design an education initiative to describe additional information that helped bridge your understanding gap to make it easier to understand.

3. Write a paper describing a genetic engineering approach to develop a new plant variety. Include the research, and the social and legal steps required to safely provide this new food to consumers.

4. As long as we have food to eat, there will be many different jobs and careers in the fields of food and food agriculture. These include rural farmers, urban farmers, scientific researchers, laboratory technicians, dieticians, food sensory experts (food tasters, food smellers), grocery store employees, chefs, bakers, farmer's market organizers, food lawyers, food photographers, food writers, and more. If you could choose any food-related career, what would it be? Write a paper about how you expect that job to change over the next 10 to 20 years, considering current and emerging biotechnologies.

5. Most of the plant crops we have today are very different from what they originally were. Choose one of the plant crops you like to eat and trace the changes that have taken place in that crop from when it was first farmed to today.

6. You are helping farmers in Africa learn how to grow a new kind of sweet potato and must educate them about the importance of this new crop from an economic and health perspective. The flesh of most of the sweet potatoes grown in Africa is white, but this new sweet potato is orange. The new sweet potato provides more Vitamin A, which would address the malnourishment that often occurs among many African women and children. Identify reasons why farmers may be resistant to growing this new, orange sweet potato. Create an information program/campaign to help the farmers understand the benefits of growing this new sweet potato.
(Source - https://phys.org/news/2019-04-sweet-potatoes-world.html)

7. You are volunteering at a children's museum and have been assigned to the Food Agriculture exhibit. Describe a hands-on activity about food agriculture that you could teach to young children (grades 3-5). How will you simplify key concepts to make them age-appropriate and understandable?

8. Science concepts can be stronger when arts and design play a central role. Choose an art form (i.e., painting, drawing, music, theater, sculpture) as the pivotal approach to explaining a concept from *Food Agriculture and Biotechnology*. Be sure to include a written explanation of the correlation through an artist's eye.

Include data, facts, and reference sources in your response. Use the **Credible Source Guide** to help choose the best sources.

CREDIBLE SOURCE GUIDE

The internet is such an extensive source of information that it can be challenging to find credible information. A credible source is one that is balanced and is written with factual evidence. Credible sources can vary with the audience, topic, and discipline. To determine if a source can be trusted, consider the following characteristic of a credible source:

Author	Information that includes an author or additional contact information can be a good indicator of credible work. An author who is willing to identify him/herself as the writer validates this site or work. The author's credibility can also be verified through searches for their background as well as for additional articles by the author.
Date	The date of research information shows whether the information is recent. The validity of older information can be confirmed by considering whether more recent information supports it.
Sources	The information found on websites or articles should have citations, i.e., list sources of the information included in the article.
Domain	Many domains (ex: .com, .org, and .net) can be purchased and used by any person or group. The domain .edu is used by higher education schools, colleges and universities; the .gov domain is reserved for government websites. Information found on the .edu and .gov domains usually host credible information, but sometimes students are given a .edu address for their personal use by universities — be careful when citing). The .org domain is usually used by non-profit organizations that may host articles or information that supports a specific perspective and is not solely educational information.
Site Design	Often, a well-designed site can indicate reliable information (however, this is very subjective). A well-designed site or article helps make information more easily accessible.
Writing Style	Poor spelling and grammar indicate that the site or article may not be credible. Credible sites carefully review writing style and grammar to ensure that information is clear, concise, and accessible to its audience.

There are always exceptions to any rule; sometimes there are credible sites and articles that don't conform to these six categories. If you are unsure that the site you are using is credible, crosscheck the information with other sources that are known to be credible, such as an encyclopedia or another reliable source about the subject.

Adapted from **https://uknowit.uwgb.edu/page.php?id=30276**

POSTER/INFOGRAPHIC RUBRIC

CATEGORIES	4	3	2	1
Required Elements	All required elements and additional information are included.	All required elements are included.	All but 1 of the required elements are included.	Several required elements were missing.
Labels	All items of importance are clearly labeled.	Almost all items of importance are clearly labeled.	Many items of importance are clearly labeled.	Labels are too small to view or no important items were labeled.
Graphics - Relevance	All graphics are related to the topic and make it easier to understand.	All graphics are related to the topic and most make it easier to understand.	All graphics relate to the topic.	Graphics do not relate to the topic.
Attractiveness	The presentation is exceptionally attractive in terms of design, layout, and neatness.	The presentation is attractive in terms of design, layout, and neatness.	The presentation is attractive but it may be a bit messy.	The presentation is poorly designed and not attractive.
Grammar	There are no grammatical/mechanical mistakes.	There are 1-2 grammatical/mechanical mistakes.	There are 3-4 grammatical/mechanical mistakes.	There are more than 4 grammatical/mechanical mistakes.

GLOSSARY AND INDEX

For the purposes of this curriculum, these terms are defined as follows.

Many of the terms below are clearly defined within the curriculum text and are listed in the index below with the page number where the definition can be found. Some additional terms that are not defined in the text and that might not be familiar to your students are defined below.

INDEX

GLOSSARY

Term	Page
Abiotic – physical (as opposed to biological), or not from living organism	35, 41
Bacterial Transformation – the use of bacterial DNA to transfer genetic material from one cell to another	25
Bioavailability – the portion of a substance that can enter circulation and become effective in a living organism	65
Biotic – a living feature	35, 41
Complementary DNA (cDNA) – single-stranded DNA synthesized from an RNA template	26
Crop Yield – a measurement of the amount of agricultural production harvested per unit of land area	24

Term	Page
Endonuclease – an enzyme that cuts a DNA or RNA strand at a location other than the ends	25
Green Revolution – a period of agricultural advances in technology that increased crop yields worldwide in the 1950s and 1960s	7
Nuclease – an enzyme that cuts DNA or RNA into smaller sections	35
Parasitoid – insect whose larvae live as parasites on and eventually kill their host	43
Repair Template (or **template DNA**) – a single strand of DNA composed of the desired sequence of nucleotides to enable the creation of the double-stranded DNA containing the correct (or desired) sequence of nucleotides.	34

Term	Page
RNA Interference (RNAi) – mechanism for eukaryotic cells to control gene expression using small RNA molecules to direct gene silencing	25
Selectable Marker (selection marker) – a gene that allows only organisms with a certain adaptation to survive under a particular condition, e.g., antibiotic exposure	27
Tillage – preparation of land to grow crops by mechanical agitation	42

FROM MODULE 1

MAKING A NEW APPLE CULTIVAR WORKSHEET ANSWERS

PART A: *APPLE, HOW DOES IT GROW?*

WWW.YOUTUBE.COM/WATCH?V=UWLMEH1HIBW

1. What is meant by the statement, "Each apple seed is genetically unique?"
   Each seed has the potential to produce a completely different apple than the one from which the seed came.

2. Explain how grafting is used to propagate new apple trees.
   In grafting, the bud from the apple cultivar the farmer wants to grow is placed in a small cut on an apple root stock. The bud and root stock fuse together and a new apple tree is produced.

3. Explain the importance of pollinators in the production of the apple crop.
   Insect pollinators are important in the cross-pollination of the apple blossoms. If the blossoms are not cross-pollinated, apples will not be produced.

4. Describe some methods that apple growers use to control pests?
   A fake apple covered with a sticky material attracts apple maggot flies. When the flies are observed on the apple, the grower knows it is time to spray.

   Insect birth control-twist ties with a pheromone in them are placed in the trees. The pheromone is released over time and sends out a scent that confuses the male insect and he never mates with the female.

5. If apples are only harvested in the late summer and fall, how are they available to consumers all year round?
   Apples are picked when they are half their ripened color and then placed in low oxygen storage, which puts the apples "to sleep."

6. How does the United States compare to other countries in the amount of apples produced?
   The United States is the second largest producer of apples in the world.

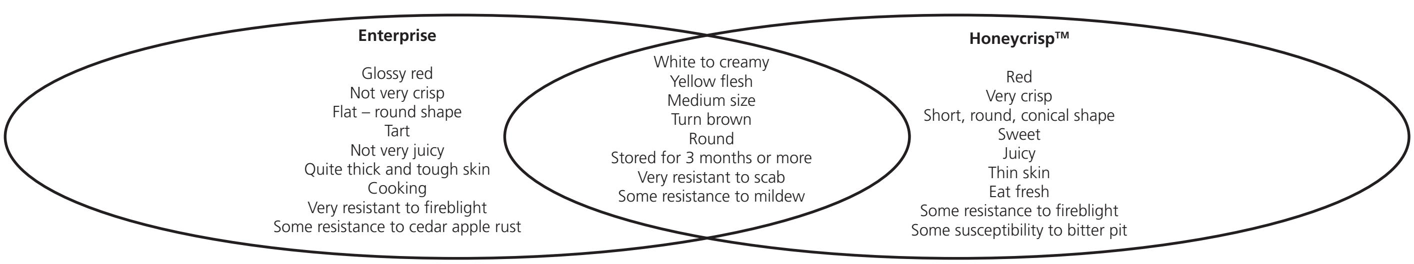
MAKING A NEW APPLE CULTIVAR WORKSHEET ANSWERS

PART B: COMPARING THE APPLE CULTIVAR TRAITS

Refer to the following websites for this activity: **www.orangepippin.com** and **www.cosmiccrisp.com/the-facts**

	Enterprise Apple	Honeycrisp™ Apple	Cosmic Crisp® Apple
Fruit Color	Glossy red	Red	Red
Flesh Color	White to cream/pale yellow	White to cream/yellow	White
Fruit Crispness	Not very crisp	Very crisp	Very Crisp
Fruit Size	Medium	Medium	Medium to large
Fruit Browning	Browns	Browns easily	Non-browning
Fruit Shape	Flat – round	Short, round, conical	Symmetrical
Fruit Taste	Tart	Sweet	Sweet/tart
Juiciness	Not very juicy	Juicy	Very juicy
Skin Thickness	Quite thick and tough	Thin	Thick
Use	Best for cooking; good for eating fresh	Best if eaten fresh	Eat fresh
Storability	3 months or more	3 months or more	3 months or more – up to a year
Disease Resistance			
Scab	Very resistant	Very resistant	
Mildew	Some resistance	Some resistance	Moderately susceptible
Fireblight	Very resistant	Some resistance	Moderately susceptible
Cedar Apple Rust	Some Resistance		
Bitter Pit		Some susceptibility	Resistant

Make a Venn diagram to explain the similarities and differences between the Enterprise and Honeycrisp™ apples.



Using the data you have collected, is there a way to determine if any of the apples' traits are dominant or recessive?

You need to know the genotypes for the traits to determine if the trait is dominant or recessive.

When comparing the Cosmic Crisp® apple to the Enterprise and Honeycrisp™ apples, what do you notice about the taste of the apples? How could the inheritance of taste be explained? Are there any other traits that seem to be similarly inherited? What would you need to do to determine whether or not your ideas for inheritance are correct?

Answers will vary. Students should notice that the Cosmic Crisp® apple is both tart and sweet. They might explain that this could be because neither trait is dominant or recessive.

Students would need to know more about the genotypes of the apples.

MAKING A NEW APPLE CULTIVAR WORKSHEET ANSWERS

PART C: DEVELOPING THE COSMIC CRISP® APPLE

Complete this worksheet as you watch the following two videos:

Why are there so many types of apples?
www.youtube.com/watch?v=mQePz62zkqA and
Farmweek – New Apple – www.youtube.com/watch?v=jZsu-_EGa_M

1. The Cosmic Crisp® apple was developed through selective breeding. Explain selective breeding and list the steps that apple breeders might use in this process.
Selective breeding is the process of choosing apples with specific traits to produce certain traits in the new apples.

- Cross-pollinate apple blossoms.
- Collect seeds from the apples.
- Grow seedlings from the seeds.
- Grown trees from the seedlings.
- Select fruit for further evaluation.
- Send selected seedlings to different locations to assess how different factors affect the growth.
- Collect and sample fruit again to ensure consistency.

2. In researching the Cosmic Crisp®, you probably did not find information about the apple's skin thickness. What might you predict the apple's skin thickness to be? What information did you use to make this prediction?
Skin thickness could be somewhat thin – based on the fact that one parent had thick skin and the other had thin skin.

3. How long was the WA 38 (Cosmic Crisp®) cultivar in development at Washington State University?
20 years

4. How do apple breeders ensure that the new apple cultivar is the same as the original seedling?
All the trees are produced from buds taken from the original tree.

5. How was the public introduction of the Cosmic Crisp® apple different than the way in which new apple cultivars are usually introduced?
There is typically limited, if any, public involvement prior to the introduction of a new cultivar; focus groups and taste testing sessions were held to expose the public to the Cosmic Crisp® apple.

6. How do apple breeders maintain long-lasting rights over an apple cultivar?
They patent and/or trademark the apple name.

7. The breeders of the Cosmic Crisp® apple believe that they have produced an apple that is better than most of the other apples available today in our grocery stores. Explain why you either agree or disagree with this statement.
Answers will vary. In their responses, students should include the favorable traits of the apple – easy to grow, stores well, does not bruise, does not turn brown when cut, etc.

8. Looking to the future, what traits would you like to see in new apple cultivars and why are these traits important?
Answers will vary but students should explain why the traits they mention are important.

STRAWBERRY DNA EXTRACTION WORKSHEET ANSWERS

1. What is DNA?
   Answers will vary. DNA is deoxyribonucleic acid – hereditary material passed from parents to offspring.

2. Where in the cell is the DNA found?
   Answers will vary. DNA is found in the nucleus of the cell.

3. What does the word extraction mean?
   Answers will vary. Extraction is to remove from or to take out of something.

4. How do you think you could extract the DNA from cells?
   Answers will vary. Accept all student responses. Students may suggest that certain chemicals are needed.

5. Does your food contain DNA, and if so, where would that DNA be found?
   Answers will vary. Students may suggest that the DNA is found in the cells of the food.

6. Each step in the extraction process aids in isolating DNA from the other cellular materials. Explain why each step was necessary and put the DNA extraction procedure into context by answering the following questions:

   Why did you have to mash the strawberries?
   To spread all the cells out as much as possible and to break down the cell walls

   What was the purpose of the salt in the DNA extracting solution?
   The salt helps the DNA precipitate out of the solution.

   What was the purpose of the liquid detergent in the DNA extracting solution?
   The detergent breaks open the cells; it breaks down the cell membrane and nuclear membrane.

   Explain what happened when you added the alcohol to the strawberry extract.
   The alcohol caused the DNA to precipitate out of the solution.

   What did the extracted DNA look like?
   It was a white, slimy solid.

7. Why is it useful for scientists to be able to extract DNA from fruits and vegetables? List at least two reasons.
   Answers will vary. Scientists can use the DNA to determine which parents to cross to produce a plant with the desired traits.

   The DNA can be used to determine if the seedlings produced by the cross breeding have the desired traits.

8. If you could extract the DNA from any fruit or vegetable, which one would you choose and why would you want to study its DNA?
   Answers will vary.

FROM MODULE 2

STUDENT WORKSHEET
SOME ANSWERS

ACTIVITY 1: GENETIC ENGINEERING

Name ______________________________ Date ______________ Class/Hour ___________

KWL CHART			
Exploration Question	**What do I know?**	**What do I want to know?**	**What did I learn?**
What is bacterial transformation?			
What is genetic engineering?			

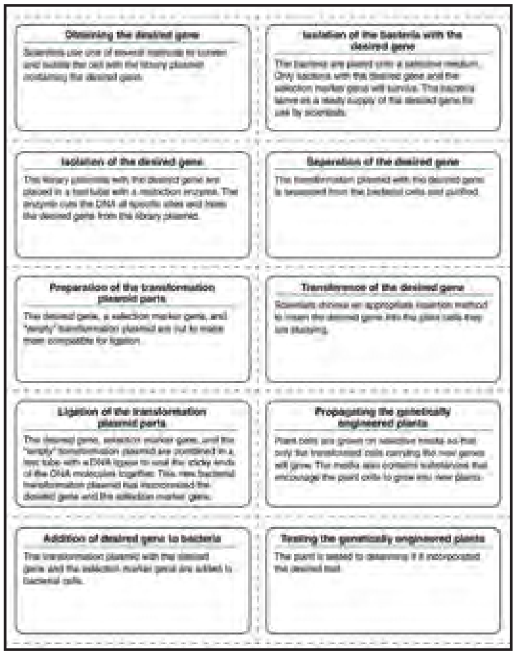
Answer the questions below after viewing these videos: *Soybean Genetic Modification* www.youtube.com/watch?v=wTraZwHDHXk, *Restriction Endonucleases (enzymes)* www.youtube.com/watch?v=5hgbcdQPISI, and *3D Animation – Bacterial Transformation* https://vimeo.com/170630548

1. What is bacterial transformation?
   Transformation is the process of introducing foreign DNA into a bacteria cell which results in newly acquired genetic trait(s) for that cell.
2. Can bacteria transform naturally? If so, how?
   Yes, they can take up DNA from the environment.
3. What are plasmids?
   Plasmids are small, circular, extrachromosomal DNA molecules found in bacteria cells. They can replicate independently of the bacteria genome and frequently carry antibiotic-resistance genes.
4. What is the role of plasmids in bacterial transformation?
   Plasmids are DNA loops that are modified and used to carry the new gene into the bacterial cell.
5. What is the role of DNA ligase?
   DNA ligase is an enzyme that joins the new gene to the plasmid.
6. Explain how the calcium chloride bath is used to insert the foreign DNA into the bacterial cell.
   Both the plasmid and the cell membrane are negatively charged, and this prevents the plasmid from entering the cell. The calcium ions are positively charged and attracted to the cell membrane and plasmid. When the cell is subjected to heat shock, the plasmid can enter the cell.
7. What happens when DNA is transcribed and replicated?
   When DNA is transcribed, it is copied into RNA. When DNA is replicated, it is copied into DNA.
8. What do the scientists do to confirm that transformation has taken place?
   A selectable marker (such as a gene for resistance to a particular antibiotic) is added to the transformation plasmid so that when the cells are plated on the selective medium with the antibiotic, only those that took up the plasmid with the marker will survive.

MODULE 2 ACTIVITY 1 ANSWERS

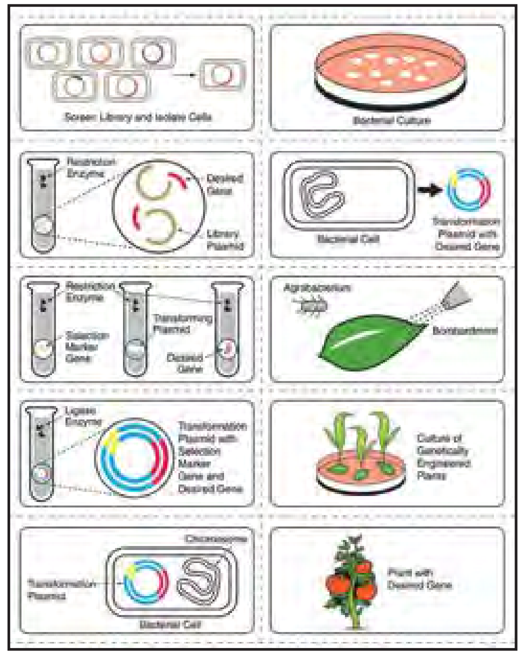
GENETIC ENGINEERING PROCESS CARDS

1. 2. 3. 4. 5.


Obtaining the desired gene
Scientists use one of several methods to screen and isolate the cell with the library plasmid containing the desired gene.
Isolation of the desired gene
The library plasmids with the desired gene are placed in a test tube with a restriction enzyme. The enzyme cuts the DNA at specific sites and frees the desired gene from the library plasmid.
Preparation of the transformation plasmid parts
The desired gene, a selection marker gene, and "empty" transformation plasmid are cut to make them compatible for ligation.
Ligation of the transformation plasmid parts
The desired gene, selection marker gene, and the "empty" transformation plasmid are combined in a test tube with a DNA ligase to seal the sticky ends of the DNA molecules together. This new bacterial transformation plasmid has incorporated the desired gene and the selection marker gene.
Addition of desired gene to bacteria
The transformation plasmid with the desired gene and the selection marker gene are added to bacterial cells.
Isolation of the bacteria with the desired gene
The bacteria are plated onto a selective medium. Only bacteria with the desired gene and the selection marker gene will survive. The bacteria serve as a ready supply of the desired gene for use by scientists.
Separation of the desired gene
The transformation plasmid with the desired gene is separated from the bacterial cells and purified.
Transference of the desired gene
Scientists choose an appropriate insertion method to insert the desired gene into the plant cells they are studying.
Propagating the genetically engineered plants
Plant cells are grown on selective media so that only the transformed cells carrying the new genes will grow. The media also contains substances that encourage the plant cells to grow into new plants.
Testing the genetically engineered plants
The plant is tested to determine if it incorporated the desired trait.

6. 7. 8. 9. 10.

1. 2. 3. 4. 5.



6. 7. 8. 9. 10.

CRISPR-CAS NOTE-TAKING GUIDE

1. Why do scientists want to be able to edit DNA?
Scientists want to edit DNA to better understand the function of specific genes. DNA editing also allows them to modify a plant genome in a very targeted way to give it favorable traits, e.g., disease-resistance, drought-tolerance.

2. What is CRISPR and how do scientists use it?
A CRISPR is a sequence of nucleotides in the bacterial genome where the bacterium keeps a record of a previous infection by a virus and later uses it to identify and fight subsequent attacks by the same or similar virus. Scientists can use these sequences, CRISPR, to change an organism's DNA.

3. In what type of organism was CRISPR first discovered?
CRISPR was discovered in bacteria.

4. What does the acronym CRISPR stand for?
Clustered Regularly Interspaced Short Palendromic Repeats

5. What is Cas?
Cas are genes that are close to CRISPR (Cas stands for "CRISPR-associated"). They code for the proteins necessary for the CRISPR system to work. Cas9 (CRISPR associated protein 9) is a protein (more specifically an enzyme) with an important role in a bacterium's immunological response to a viral infection. It is used in genetic engineering to induce targeted double-stranded breaks in DNA.

6. How did scientists harness or program the CRISPR-Cas9 system they identified in bacteria?
They discovered that during the process, the two RNAs pair up and recruit Cas9 protein and direct it to bind to the target DNA and cut it. They then designed a guide RNA molecule that could recruit Cas9 and cut DNA in plasmids where they wanted, insert a gene, and allow the cell to close the loop.

7. Describe the steps in the CRISPR-Cas system.
1. Identify the gene responsible for the desired trait and design a piece of guide RNA and an enzyme to target that gene. 2. Introduce the guide RNA and the restriction enzyme into a cell. 3. The guide RNA locates and binds to the DNA sequence, and its Cas9 enzyme then cuts the DNA at the targeted location. 4. Add or remove a target section of DNA depending on the desired new trait. 5. Allow the cell to naturally repair itself. 6. Remove the guide RNA and Cas9. 7. The resulting plant can be crossed with the original one, and the change is then passed on to the offspring.

8. List some potential benefits/applications of CRISPR technology for our food.
Increase yields, reduce allergens such as gluten, make food more nutritious or enhance flavor, make plants more impervious to drought and pests, or change the growing season of crops

FROM MODULE 3

STUDENT WORKSHEET
SAMPLE ANSWERS
ACTIVITY 1: AGRICULTURAL PESTS

Name ____ Date _____________ Class/Hour __________

Write your working definition for agricultural pests here: ____

____

____

This answer key provides examples of the pests and beneficial insects and plants that students will find through their research.

DATA TABLE

Name and Kind of Organism	Pest or Beneficial	Action
1. Russian wheat aphid	Pest	Feeds on wheat, barley, oats
2. Phytophthora ramorum – water mold	Pest	Feeds on tanoak and coastal live oak in California and Oregon
3. Brown stink bug – insect	Pest	Feeds mainly on fruit trees but also other plants – eastern United States
4. Hessian fly – insect	Pest	Feeds on winter wheat – southeastern United States
5. Two-spotted spider mite – mite	Pest	Feeds on vegetable and food crops
6. Asian citrus psyllid – insect	Pest	Feeds on all citrus trees
7. Honey bee – insect	Beneficial	Pollinates flowers
8. Giant African snail – mollusk	Pest	Feeds on fruit and vegetable plants
9. Long-jawed orb weaver – spider	Beneficial	Eat flies, moths, and other insects
10. Lady beetle – insect	Beneficial	Feeds on aphids and scale insects
11. Nasturtium – weed	Beneficial	Repels insect pests; crowds out other weeds

List the pests that affect the plants shown in the video, *The Amazing Way Plants Defend Themselves*
https://ed.ted.com/lessons/the-amazing-ways-plants-defend-themselves-valentin-hammoudi

Answers: Insects (aphids, caterpillars, grasshoppers); small and large herbivores (tortoises, koala bears, elephants); fungi, bacteria, microbes

List the pests that affect agricultural crops shown in the video, *Do We Really Need Pesticides*?
https://ed.ted.com/lessons/do-we-really-need-pesticides-fernan-perez-galvez#review

Answers: Insects, fungi, unwanted weeds, rodents, bacteria

Final working definition for agricultural pests: ____

____

____

STUDENT WORKSHEET

ACTIVITY 2: PEST MANAGEMENT RESEARCH PROJECT SAMPLE ANSWERS

Group Members ______________________________ Pest ______________________

Use the tables below to collect data for your poster.

PEST		
Description of Pest	**Native/Non-Native (Where it came from and how it got here)**	**Life Cycle Most Dangerous to Crop**
Giant African Snail	East Africa	Adult
Crop(s) Affected	**Damage to Crop**	**Number of Individual Pests Present to Significantly Harm Crop**
500 different kinds of plants – including all crops grown in Florida	Crops could be destroyed	One can lay 100 – 500 eggs; highly invasive

PEST MANAGEMENT OPTIONS			
Management Method	**Environmental Impact**	**Effectiveness**	**Data Source(s)**
Iron Phosphate	Does not affect the quality of the human environment (proper use and handling required)	Very effective when used in combination with boric acid and physical removal	University of FL; APHIS
Metaldehyde	Use with caution around birds and mammals (proper use and handling required)	When used in conjunction with other methods increases their effectiveness	University of FL; APHIS
Boric Acid	Does not significantly affect the quality of the human environment (proper use and handling required)	Very effective when used in combination with iron phosphate and physical removal	University of FL; APHIS
Physical removal	Plants not destroyed	Very effective when used in combination with boric acid and iron phosphate	University of FL; APHIS

Best possible management solution(s).

According to APHIS, the most effective management program includes physical removal, iron phosphate, and boric acid. In some areas, Metaldehyde has been approved for use in conjunction with physical removal, iron phosphate, and boric acid.

Note any data you find about the environmental impact of the best management solution(s), using **+** for positive impact, **—** for negative impact and **0** for no impact.

Air Quality	0	Pollinators	0	Human Health	0
Biodiversity	0	Wildlife	— Some birds	Surface Water	0
Groundwater	0	Soil Fauna	0	Irrigation	0
CO_2 Emissions	0	Estuaries	0	Fossil Fuels	0
Waste	0	Methane Emissions	0	Desertification	0
Sustainability	0	Government Policy	0	Flora	0

STUDENT WORKSHEET
SAMPLE ANSWERS
ACTIVITY 3: CITRUS GREENING DISEASE

Name ______________________________ Date ____________ Class/Hour __________

Answer the following questions as you watch these two videos:
Bitter Fruit - Citrus Greening Disease Threatens Florida Industry www.youtube.com/watch?v=T5nqVmliUaM and
Citrus Greening Disease www.youtube.com/watch?v=G_1sobDdtiM.

1. What is citrus greening disease and what are its symptoms?
Citrus greening disease is a bacterial infection that impacts all kinds of citrus plants. Symptoms: fruit falls prematurely, fruit is misshapen, juice is very bitter.

2. What is the name of the bacterium that causes the disease?
Candidatus Liberibacter asiaticus

3. How does the disease spread in a citrus grove?
Psyllid insects transfer the bacterium from one plant to another. The bacteria live in the sap of the plant. The insects feed on the sap and ingest the bacteria and carry the bacteria from one tree to another.

4. How widespread is this disease in the United States?
The disease is now in all counties in FL that grow citrus, GA, AL, MS, LA, TX, CA, SC, AZ.

5. Which groups of people are impacted by citrus greening disease?
The disease impacts growers, producers, juicers, and consumers.

6. What is the research objective of the scientists' work in the video?
Scientists are trying to understand how the bacteria are spread and to develop new ways to block it from spreading in a grove.

7. What is the hypothesis for their research?
Scientists are interested in the disease transmission process. Not all insects are able to transmit the bacteria. They are trying to find out why some insects transmit the disease and some do not.

8. What happens to the bacterium in the body of a psyllid that enables it to be transmitted from one citrus tree to another?
The bacteria need to be able to travel through the body of the insect, penetrate cell membranes, enter salivary glands, and reproduce inside the insect.

9. List the 4 steps in the Detached Leaf Transmission Assay.
1. Set up healthy leaves 2. Collect exposed insects from diseased leaves 3. Put exposed insects on healthy leaves 4. Allow insects to feed on leaves for 7 days

10. How do the scientists detect the bacteria in the infected leaves and why do they use this method?
Scientists look for the DNA of the disease-causing bacteria, which can be detected in just 7 days, because trees can take years to exhibit visible signs of the disease.

11. What did the scientists learn through their research?
The scientists learned that some populations of insects transmitted the bacteria while others did not.

12. What do the scientists hope to eventually be able to do with their information?
By studying the biology of the different populations of insects, they will learn why some transmit the bacteria and others do not.

13. Why do you think this research is important?
Students should use the information from the video to answer this question.

14. If you could use Genetic Engineering to create a way to control HLB, what would you design, and which pest control method would it use? ____

____

CITRUS GREENING MANAGEMENT PROGRAMS DATA TABLE SAMPLE ANSWERS

Manage-ment Program	Management Description	Effectiveness of Treatment	Environmental Impact	Part of Tree Treated	Where Used and Frequency
Parasitic wasps – *Tamarixia Radiata*	Classical biocontrol: wasp lays egg inside body of psyllid nymph; wasp larva feeds on nymph, killing it. Adult wasp emerges from nymph's thorax. Adult wasps also feed on younger nymphs	Slows spread of disease; only works when population of psyllids is low	Wasps only known to attack psyllids	Psyllid nymph inside the tree	Arizona, Florida, California, Puerto Rico Used as long as psyllids are present
Nutrition	Diagnosis and Recommendation Integrated System (DRIS) used to analyze trees and determine fertilizer needed.	HLB stunts feeder roots and causes nutrient deficiencies in roots and canopies. Applying the proper amount of the deficient nutrients helps the tree fight HLB.		Leaves and roots	Florida
Reflective mulch	Material such as aluminum or silver polyethlyne mulches reflect light up onto the plants & may impair psyllids' ability to find the tree; mulch together with fertigation* helps tree come into production more quickly.	Has been successful with certain vegetable crops; canopy of older trees shade the mulch	Requires less fertilizer, water, and herbicide vs. bare ground	Used under newly planted trees.	Florida, California, Brazil
Heat treatment	Mature trees are encased in plastic tent – sun heats air; or, steam is used. Seedlings are grown in greenhouses	Slows or diminishes psylid count; kills some of bacteria; may prolong production and/or growth of tree		Tree	Implementation challenges on a large scale; height of trees is an issue. In use until a successful method can be found to eliminate the disease.
Bactericides	Topical treatment; not absorbed by tree or fruit; streptomycin and oxytetracycline	Slows bacterial growth; depends on number of treatments and when and kind of adjuvant**. Unproven	May be unsafe long-term. May block tree's transport system. Approved for other crops.	Tree	Florida New for citrus; successful for pear and apple trees. More research needed for optimal application strategy
Bactericides	Injected in trunk of tree - streptomycin and oxytetracycline	Costly. Ensures that light and rainfall don't degrade bactericide. Unproven	May be unsafe long-term. May block tree's transport system. Approved for other crops.	Leaves and roots	Florida
Bactericide - Zinkicide	Nanotechnology – reaches deep inside tree where bacteria are found; laser injected; can also be applied as a leaf spray or soil drench; kills CLas	Experiments started in 2015	Safe for bees and other beneficial insects; derived from ingredients found in plants; metabolized after job is done	Leaves, roots	Florida

CITRUS GREENING MANAGEMENT PROGRAMS DATA TABLE SAMPLE ANSWERS (CONTINUED)

Manage-ment Program	Management Description	Effectiveness of Treatment	Environmental Impact	Part of Tree Treated	Where Used and Frequency
CUPS - Citrus Under Protective Screen	Trees are grown under screens; grapefruit grown hydroponically in greenhouse - produce fruit in 1 year; those grown outdoors under screens produce early; IPM with biocontrol, hydroponics/ irrigation, suitable rootstock varieties	Psyllid can be completely excluded.	May reduce insecticide, fertilizer, and water use. Protects from other insects.	Tree	Florida, California; year-round. Research is ongoing.
Traditional Breeding	Tree produced through traditional breeding methods. 10,000 hybrids have been tested for both yield and tree health. A few promising cultivars have been found.	Tree bred for other purposes; inadvertently found to produce more phloem when CLas block phloem; more testing needed.	Trees are able to survive infection by CLas. Trees still harbor CLas so psyllid can spread it to other trees.	Rootstock	Florida, California. Sugar Belle is a hybrid of sweet Clementine & Minneola tangerine
Genetically engineered plants	Tree engineered with genes from spinach. Spinach genes cause citrus tree to produce defensive proteins. NOTE: see CTV - virus can be used to deliver proteins.	Trees in both greenhouses and field show continued resistance over 2nd and 3rd generations.		Tree - inner most layer of bark	Florida
CRISPR-Cas 9	Would be used to modify key citrus genes to be unresponsive to CLas	Has been successful in developing canker-resistant citrus		Scions and rootstocks	Florida. Still in research
Genetically engineered virus – Citrus tristeza virus (CTV)	CTV is genetically engineered to use defensin proteins from spinach to manage the disease. Virus is injected into a young tree; when tree matures, shoots are taken from it and grafted onto healthy and infected trees.	Tree produces defensin, which protects tree from contracting disease or treats infected trees. Defensin pokes holes in bacteria's membranes causing them to lose fluids.	The spread of the virus to others trees is not expected. CTV is already found in citrus. Defensin is found in spinach, potatoes, wheat and sunflowers. The virus is not expected to travel beyond the inoculated tree.	Young trees	Florida, California Experimental — Acreage expansion is needed.
Insecticide	Synthetic; sprayed at flush time, i.e., when the tree is in full bloom	Several different kinds needed; long-term costs too high for growers	Insects develop resistance	Leaves	Florida Need to spray 3 or 4 times a year when trees are in flush.
Bioinsecti-cide	Challenger - contains a fungus that acts as a parasite to the psyllids, killing them.	Almost as effective as synthetic insecticides, but more expensive.		Insect	Brazil Has been used since 2018; more research needed.

* The injection of fertilizers, soil amendments and other water-soluble products into an irrigation system.
**adjuvant - second chemical used in combination with a compound that increases its effectiveness by, for example, prolonging its stickiness to the tree

STUDENT WORKSHEET

MALNUTRITION REPORT
SOME ANSWERS

Name ______________________________ Date ____________ Class/Hour __________

1. How do you know that the Hunger Map (provided) is a credible source?
(This is from the World Health Programme, a part of the United Nations, and there are citations.)

2. Which countries exhibit undernourishment for greater than 35% of their population?
(As of 2019: Central African Republic, Haiti, Liberia, Madagascar, North Korea, Rwanda, Uganda, Zambia, and Zimbabwe)

3. Choose one of those countries for your report on malnutrition. Which country did you choose? Why?
____

4. Sketch the shape of the country you chose and identify on which continent this country is located.

5. Describe the country's climate. ____
____

6. Complete the chart below using the Credible Source Guide.

Question	Answer(s) From Your Research	Citation: Title/Website Address
a. Identify one nutrient that this country struggles to provide its population.		
b. What percentage of the population suffers from malnourishment?		
c. What crops are grown in this country?		
d. Which foods are considered the staples in this country (rice, beans, cassava)?		
e. What are the reported causes of malnourishment in this country (environmental, economic, etc.)?		

Student answers will vary on the second page of this worksheet, so a sample page is not included.

STUDENT WORKSHEET

NEW PLANT VARIETY
SAFETY EVALUATION PROCESS SAMPLE ANSWERS

There are dozens of potato varieties that are grown in the United States. Your research team will genetically engineer a new potato variety from a host plant, the Yukon Gold potato.

Your project is to alter a trait that reduces susceptibility to one of the following three conditions:

☐ bruising ☐ blight ☐ insect damage (Choose one)

You are making a genetically engineered new variety. Decide how you want to alter the DNA.

Will you ☐ insert a transgene (a gene from another organism) or use ☐ genome editing?

Research your "host" potato variety using the internet (refer to the Credible Source Guide). First, look at Organisation for Economic Cooperation and Development) Potato composition document (pages 15 - 21) **https://www.oecd.org/env/ehs/biotrack/46815167.pdf**. The National Agricultural Library has many good sources, including FoodData Central **https://fdc.nal.usda.gov/**. Search for a specific potato, e.g., Yukon Gold, or you will get too much information. Complete the table below and record your sources.

Use the Safety Evaluation Process flow chart as a guide to determine if your new potato variety is "as safe and nutritious as comparable food" or if "additional information is needed." Your variety is hypothetical, so you have not actually tested its final composition in a laboratory. As you consider the flow chart questions (blue diamonds), you might not have enough information about your new variety to answer "yes" or "no." Choose a hypothetical answer to describe your variety, and circle the "yes" or "no" answer.

Potato Composition (% fresh weight, %FW)	A. Host Plant (Yukon Gold Potato)	B. New DNA (inserted or altered)	C. New Potato Variety	Credible Sources for A. and B. Data
Nutrient composition (starch, protein, fat, Vitamin C, potassium, etc.)	Starch: avg. 17.5% (range 8 - 29.4%) Protein: avg. 2% (range 0.69-4.63%) Fat: avg. 0.12% (range: 0.02-0.2%) Vitamin C: avg. 100-250 mg/kg (range 10-540 mg/kg) Potassium: range 0.22-0.94%		within the normal range	A. https://www.oecd.org/env/ehs/biotrack/46815167.pdf B: https://fdc.nal.usda.gov/fdc-app.html#/food-details/472938/nutrients C. https://geneticliteracyproject.org/2015/05/27/scientist-and-mom-evaluates-simplots-gmo-innate-potato/
Naturally-occurring toxins	Glycoalkaloids (e.g., solanine, chaconine)		within the normal range of safety (200 mg total glycoalkaloids or less per 1 kg of potato)	https://www.oecd.org/env/ehs/biotrack/46815167.pdf
Naturally-occurring anti-nutrients	Protease inhibitors & lectins		within the normal range	https://www.oecd.org/env/ehs/biotrack/46815167.pdf
Naturally-occurring allergen(s), if any	Patatin		No difference	https://www.oecd.org/env/ehs/biotrack/46815167.pdf

Would you expect amino acids or proteins created through the change in DNA be present in the new potato? ______________

Is your new potato variety... ☐ "as safe and nutritious as comparable food" or ☐ "additional information is needed" (select one).

Explain your decision. ____

____

STUDENT WORKSHEET

ARE THERE INGREDIENTS FROM GE PLANTS IN MY FOOD? ANSWERS

Teacher Note: This answers for this activity may change over time as products change. Check for new products in the FDA biotech inventory **https://www.fda.gov/food/consultation-programs-food-new-plant-varieties/final-biotechnology-consultations** and on the USDA/AMS website **https://www.ams.usda.gov/rules-regulations/be/bioengineered-foods-list**.

Look at each **Food Label** card and think about the ingredients in that item. If there isn't a label, research the food or beverage to find out what ingredients it might contain. After you have determined which group the food belongs to (GE/possible GE or Non-GE), put a check mark in that box below and list the reason(s) for that choice.

Food Card item	Marketing label, e.g., organic	Food or ingredients that may come from GE crops	GE or Possibly GE	Food or ingredients with no corresponding GE counterpart	Non-GE
Arctic Apple			✓		
Cinnamon Crunch Cereal		Sugar; canola oil; fructose; maltodextrin; soy lecithin	✓		
Clementines					✓
Coffee					✓
Cosmic Crisp Apple					✓
Cottage Cheese	Organic				✓
Cream Filled Cookies		Sugar; canola oil; high fructose corn syrup; corn starch	✓		
Cut Green Beans	Organic				✓
Graham Crackers	Organic				✓
Granola Bars	BE	Soy protein; sugar	✓		
Honey Nut Oat Cereal		Sugars; corn starch	✓		
Margarine	Non-GMO				✓
Orange Juice					✓
Pita Bread		Corn starch; soy oil	✓		
Rainbow Papaya			✓		
Seedless Watermelon					✓
Sour Cream				No GE dairy cows currently used in milk production.	✓
Table Salt				Cannot be GE because it is not derived from an organism and so has no DNA.	✓
Tea	Organic				✓
Wheat Bread		Sugar; soybean oil; soy lecithin; soy	✓		

SCIENCE AND OUR FOOD SUPPLY

Exploring **Food Agriculture** and **Biotechnology**

Education Standards by Activity

	Apple Cultivar	Straw-berry DNA	GE	Target. Genome Editing	Pest ID	Pest Mgmt	Citrus Greening	Global Nutrition	Safety Eval.	Labeling
NGSS - Physical Science: Structure and Properties of Matter	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
NGSS - Life Science: Structure and Function	✔	✔	✔	✔		✔	✔	✔	✔	✔
NGSS - Life Science: Matter and Energy in Organisms and Ecosystems	✔		✔	✔				✔		✔
NGSS - Life Science: Interdependent Relationships in Ecosystems	✔		✔	✔	✔	✔	✔	✔		
NGSS - Life Science: Inheritance and Variation of Traits	✔		✔	✔		✔	✔	✔		
NGSS - Life Science: Natural Selection and Evolution	✔					✔				
NGSS - Engineering: Engineering Design	✔		✔	✔	✔	✔	✔	✔	✔	✔
AL - Agriculture & the Environment	✔		✔	✔	✔	✔	✔	✔		
AL - Plants & Animals for Food, Fiber & Energy	✔		✔	✔	✔	✔	✔	✔	✔	✔
AL - Food, Health & Lifestyle								✔	✔	✔
AL - Science, Technology, Engineering & Mathematics	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
AL - Culture, Society, Economy & Geography	✔		✔	✔	✔	✔	✔	✔	✔	✔
NSFCSE 3.0 - Career, Community & Family Connections	✔				✔	✔	✔	✔	✔	✔
NSFCSE 3.0 - Consumer & Family Resources	✔		✔	✔	✔	✔	✔	✔	✔	✔
NSFCSE 3.0 - Consumer Services						✔				✔
NSFCSE 3.0 - Food Science, Dietetics, & Nutrition	✔				✔	✔	✔	✔	✔	✔
NSFCSE 3.0 - Nutrition & Wellness	✔				✔	✔	✔	✔	✔	✔
NHES (2)	✔		✔	✔	✔	✔	✔	✔	✔	✔
NHES (3)								✔	✔	✔
CCSS - ELA-Literacy	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CCSS - Math								✔	✔	✔
NCSS - Time, Continuity, & Change	✔		✔	✔		✔	✔	✔	✔	✔
NCSS - Production, Distribution, & Consumption	✔		✔	✔		✔	✔	✔	✔	✔
NCSS - Science, Technology, & Society	✔		✔	✔	✔	✔	✔	✔	✔	✔

See next pages for full standards: NGSS, AL, NSFCSE, National Health Education Standards, Common Core Math and ELA/Literacy, and NCSS

EDUCATION STANDARDS

Science and Our Food Supply: Exploring Food Agriculture and Biotechnology aligns with the following current education standards:

NGSS – Next Generation Science Standards Arranged by Topic

Physical Science

Structure and Properties of Matter

- HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Life Science

Structure & Function

- HS-LS1-1 Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

Matter & Energy in Organisms & Ecosystems

- HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

Interdependent Relationships in Ecosystems

- HS-LS2-6 Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
- HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- HS-LS4-6 Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

Inheritance & Variation of Traits

- HS-LS1-4 Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.
- HS-LS3-1 Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
- HS-LS3-2 Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
- HS-LS-3-3 Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Natural Selection & Evolution

- HS-LS4-2 Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

Engineering Design

- HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

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National Agricultural Literacy Outcomes (AL)[1]

Agriculture & the Environment

- T1.9-12.b Describe resource and conservation management practices used in agricultural systems (e.g., riparian management, rotational grazing, no till farming, crop and variety selection, wildlife management, timber harvesting techniques)
- T1.9-12.c Discuss the scientific basis for regulating the movement of plants and animals worldwide to control for the spread of potentially harmful organisms (e.g., invasive species and disease causing organisms such as foot and mouth disease and avian and swine flu) as well as the methods of control in place (state, national, and international policies, economic incentives)
- T1.9-12.d Discuss the value of agricultural land
- T1.9-12.f Evaluate the various definitions of "sustainable agriculture," considering population growth, carbon footprint, environmental systems, land and water resources, and economics
- T1.9-12.h Understand the natural cycles that govern the flow of nutrients as well as the way various nutrients (organic and inorganic) move through and affect farming and natural systems

Plants & Animals for Food, Fiber & Energy

- T2.9-12.b Compare similarities and differences between organic and inorganic nutrients (i.e., fertilizer) on plant growth and development; determine how their application affects plant and animal life
- T2.9-12.c Discuss reasons for government's involvement in agricultural production, processing, and distribution
- T2.9-12.d Evaluate evidence for differing points of view on topics related to agricultural production, processing, and marketing (e.g., grazing; genetic variation and crop production; use of fertilizers and pesticides; open space; farmland preservation; animal welfare practices; world hunger)
- T.9-12.e Identify inspection processes associated with food safety regulations

Food, Health & Lifestyle

- T3.9-12.a Accurately read labels on processed food to determine nutrition content
- T3.9-12.e Explain food labeling terminology related to marketing and how it affects consumer choices (e.g., natural, free-range, certified organic, conventional, cage-free, zero trans-fat, sugar-free, reduced calorie)
- T3.9-12.h Provide examples of foodborne contaminants, points of contamination, and the policies/agencies responsible for protecting the consumer

Science, Technology, Engineering & Mathematics

- T4.9-12.a Correlate historical events, discoveries in science, and technological innovations in agriculture with day-to-day life in various time periods
- T4.9-12.b Describe how agricultural practices have contributed to changes in societies and environments over time
- T4.9-12.c Discuss population growth and the benefits and concerns related to science and technologies applied in agriculture to increase yields and maintain sustainability
- T4.9-12.d Evaluate the benefits and concerns related to the application of technology to agricultural systems (e.g., biotechnology)
- T4.9-12.e Identify current and emerging scientific discoveries and technologies and their possible use in agriculture (e.g., biotechnology, bio-chemical, mechanical, etc.)
- T4.9-12.f Predict the types of careers and skills agricultural scientists will need in the future to support agricultural production and meet the needs of a growing population

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[1] Spielmaker, D. M., & Leising, J. G. (2013). National agricultural literacy outcomes. Logan, UT: Utah State University, School of Applied Sciences & Technology. Retrieved from http://agclassroom.org/teacher/matrix

Culture, Society, Economy & Geography

- T5.9-12.a Communicate how the global agricultural economy and population influences the sustainability of communities and societies
- T5.9-12.c Compare and contrast the economic challenges facing developed and under-developed countries (poverty, population, and hunger)
- T5.9-12.e Discuss how agricultural practices have increased agricultural productivity and have impacted (pro and con) the development of the global economy, population, and sustainability
- T5.9-12.f Discuss the relationship between geography (climate and land), politics, and global economies in the distribution of food
- T5.9-12.i Explain the role of government in the production, distribution, and consumption of food
- T5.9-12.j Provide examples of how changes in cultural preferences influence production, processing, marketing, and trade of agricultural products

Family & Consumer Sciences National Standards 3.0

1.0 Career, Community & Family Connections

- 1.1.1 Summarize local and global policies, issues, and trends in workplace, community, and family dynamics that affect individuals and families.
- 1.1.2 Analyze the effects of social, economic, and technological changes on work and family dynamics.
- 1.3.5 Analyze the effects of federal, state, and local public policies, agencies, and institutions on the family.

2.0 Consumer & Family Resources

- 2.1.3 Analyze decisions about providing safe and nutritious food for individuals and families.
- 2.3.1 Analyze state and federal policies and laws providing consumer protection.

3.0 Consumer Services

- 3.5.6 Evaluate the labeling, packaging, and support materials of consumer goods.

9.0 Food Science, Dietetics, & Nutrition

- 9.1.1 Explain the roles and functions of individuals engaged in food science, food technology, dietetics, and nutrition care.
- 9.3.1 Analyze nutrient requirements across the life span addressing the diversity of people, culture, and religions.
- 9.3.2 Analyze nutritional data.
- 9.3.4 Assess the influence of cultural, socioeconomic and psychological factors on food and nutrition and behavior.
- 9.5.1 Analyze various factors that affect food preferences in the marketing of food to a variety of populations.
- 9.6.6 Analyze new products utilizing most current guidelines and innovations in technology.
- 9.7.7 Analyze the impact of food presentation methods and techniques on nutrient value, safety and sanitation, and consumer appeal of food and products.

14.0 Nutrition & Wellness

- 14.1.2 Investigate the effects of psychological, cultural, and social influences on food choices and other nutrition practices.
- 14.1.3 Investigate the governmental, economic, and technological influences on food choices and practices.
- 14.1.4 Analyze the effects of global, regional, and local events and conditions on food choices and practices.
- 14.1.5 Analyze legislation and regulations related to nutrition and wellness.
- 14.2.4 Analyze sources of food and nutrition information, including food labels, related to health and wellness.
- 14.4.3 Analyze how changes in national and international food production and distribution systems influence the food supply, including sustainability, organic food production and the impact of genetically modified foods.
- 14.4.4 Investigate federal, state, and local inspection and labeling systems that protect the health of individuals and the public.

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- 14.5.1 Investigate how scientific and technical advances influence the nutrient content, availability, and safety of foods.
- 14.5.2 Analyze how the scientific and technical advances in food processing, storage, product development, and distribution influence nutrition and wellness.
- 14.5.4 Analyze the effects of food science and technology on meeting nutritional needs.

National Health Education Standards

(2) Analyze the influence of family, peers, culture, media, technology, and other factors on health behaviors.

- 2.12.2 Analyze how the culture supports and challenges health beliefs, practices, and behaviors.
- 2.12.5 Evaluate the effect of media on personal and family health.
- 2.12.6 Evaluate the impact of technology on personal, family, and community health.
- 2.12.10 Analyze how public health policies and government regulations can influence health promotion and disease prevention.

(3) Demonstrate the ability to access valid information, products and services to enhance health.

- 3.12.1 Evaluate the validity of health information, products, and services.

Common Core State Standards, ELA-Literacy

- RI.9-10.1 & RL.9-10.1 Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.
- RI. 9-10.5 Analyze in detail how an author's ideas or claims are developed and refined by particular sentences, paragraphs, or larger portions of a text (e.g., a section or chapter).
- RI.9-10.7 Analyze various accounts of a subject told in different mediums (e.g., a person's life story in both print and multimedia), determining which details are emphasized in each account.
- RI.9-10.8 Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is valid and the evidence is relevant and sufficient; identify false statements and fallacious reasoning.
- W.9-10.1 Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
- W.9-10.2 Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.
- W.9-10.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- W.9-10.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- W.9-10.6 Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- W.9-10.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- W.9-10.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- W.9-10.9 Draw evidence from literary or informational texts to support analysis, reflection, and research.
- W.9-10.10 Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences.
- SL.9-10.1 Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on *grades 9–10 topics, texts, and issues,* building on others' ideas and expressing their own clearly and persuasively.

- SL.9-10.2 Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.
- SL.9-10.4 Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.
- SL.9-10.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.
- L.9-10.1 Demonstrate command of the conventions of standard English grammar and usage when writing or speaking.
- L.9-10.2 Demonstrate command of the conventions of standard English capitalization, punctuation, and spelling when writing.
- L.9-10.6 Acquire and use accurately general academic and domain-specific words and phrases, sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when considering a word or phrase important to comprehension or expression.
- RH.9-10.1 Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
- RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- RST.9-10.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- RST.9-10.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9–10 texts and topics*.
- RST.9-10.5 Analyze the structure of the relationships among concepts in a text, including relationships among key terms.
- RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.
- RST.9-10.9 Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
- WHST.9-10.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.
- WHST.9-10.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- WHST.9-10.6 Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- WHST.9-10.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- WHST.9-10.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- WHST.9-10.9 Draw evidence from informational texts to support analysis, reflection, and research.

Common Core State Standards, Math

- S-CP Understand independence and conditional probability and use them to interpret data.

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NCSS - National Curriculum Standards for Social Studies

Time, Continuity, & Change

Learners will understand:

- The importance of knowledge of the past to an understanding of the present and to informed decision-making about the future.

Production, Distribution & Consumption

Learners will understand:

- Scarcity and the uneven distribution of resources result in economic decisions, and foster consequences that may support cooperation or conflict.
- That regulations and laws (for example, on property rights and contract enforcement) affect incentives for people to produce and exchange goods and services.
- Entrepreneurial decisions are influenced by factors such as supply and demand, government regulatory policy, and the economic climate.

Science, Technology, & Society

Learners will understand:

- Science and technology have had both positive and negative impacts upon individuals, societies, and the environment in the past and present.
- Decisions regarding the uses and consequences of science and technology are often complex because of the need to choose between or reconcile different viewpoints.
- Science, technology, and the consequences are unevenly available across the globe.
- Science and technology have contributed to making the world increasingly interdependent.
- That achievements in science and technology are increasing at a rapid pace and can have both planned and unanticipated consequences.
- Developments in science and technology may help to address global issues.

Science and Our Food Supply: Exploring Food Agriculture and Biotechnology was brought to you by...

U.S. FOOD & DRUG ADMINISTRATION

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College Park, MD

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Office of Food Additive Safety
Office of Nutrition and Food Labeling
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USDA

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