BIOTECHNOLOGY

Genetic improvement method: mutagenesis

Focus questions	How are breeding techniques being used in agriculture to solve problems? How might mutations in DNA lead to both natural variation and beneficial traits in agricultural crops?
Learning target	Students become aware of mutagenesis as a technique to change plant DNA to produce beneficial traits.
Vocabulary	Gene mutation, point mutation, mutagenesis, codon, transcription, translation, amino acid sequence, induced mutagenesis, ionizing radiation, protein synthesis

HS-LS3: Heredity: Inheritance and Variation of Traits

Performance expectation HS-LS3–1 HS-LS3–2	**Classroom connection:** Students directly model how DNA mutations occur and explore how these changes affect protein structure. They examine real-world applications where induced mutagenesis has created valuable crop varieties, connecting molecular biology to agricultural innovation.

Science and engineering practices

Developing and Using Models	**Classroom connection:** Students create concrete models of the central dogma (DNA → RNA → protein) and use these models to trace how a single nucleotide change occurs through biological systems.
Analyzing and Interpreting Data	**Classroom connection:** Students analyze data from their models to draw conclusions about mutation effects and evaluate real agricultural examples.

Disciplinary core ideas

LS3.A: Inheritance of Traits **LS3.B: Variation of traits**	**Classroom connection:** Students observe how DNA codes for specific amino acid sequences and how mutations alter these sequences. They explore induced mutagenesis as a deliberate application of mutation biology, examining how radiation-induced changes have produced improved crop varieties.

Cross-cutting concepts

Cause and Effect	**Classroom connection:** Students trace cause-and-effect relationships from molecular changes (DNA mutation) to molecular consequences (altered protein) to organism outcomes (new traits).

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

Background

DNA serves as the instruction manual for all living organisms, storing information in sequences of four nucleotides (A, T, G, C). This information is read in groups of three nucleotides called **codons**. Through transcription, DNA is copied into messenger RNA (mRNA), which travels to ribosomes where translation occurs, using transfer RNA (tRNA) to gather amino acids that fold into proteins. **Mutations** are changes in DNA sequences. While some mutations are harmful, many are neutral or even beneficial. **Point mutations** change a single nucleotide, which may or may not change the resulting amino acid due to repeats within the genetic code. When mutations do change amino acids, they can alter protein function, potentially creating new traits. **Induced mutagenesis** uses radiation or chemicals to deliberately create mutations at higher rates than those that would occur naturally. Scientists then screen thousands of mutated organisms to find rare beneficial changes. This technique has been used since the 1920s and has produced over 3,000 crop varieties, including Ruby Red grapefruit, disease-resistant rice varieties, and countless ornamental flowers. Unlike genetic engineering, mutagenesis doesn't move genes between species—it simply speeds up natural mutation processes.

Prior knowledge

- Basic DNA structure (nucleotides, base pairing rules: A–T, G–C)
- Basic exposure to the concepts of transcription and translation (can be introduced during this lesson)
- DNA contains instructions for making proteins
- Proteins perform most cellular functions
- Changes in organisms can result from genetic changes

Suggested timing

1–2 class periods

Materials

Per student or pair of students:

- Student handout with DNA sequences
- Codon chart (genetic code table)
- Colored pencils or highlighters (3–4 colors)
- Access to computers/tablets for research

For class:

- Large codon chart poster or projection
- Examples of mutagenesis-derived foods (optional: Ruby Red grapefruit, photos of rice varieties)
- Whiteboard/chart paper for class discussion

Teacher preparation

1. Print materials: ensure each student has the handout with DNA sequences and codon chart.
2. Set up technology: prepare computers/tablets for research portion.
3. Review content: familiarize yourself with the differences between the original and mutated sequences (i.e. Histidine to Valine substitution).
4. Prepare visuals: display a large codon chart and have examples of central dogma flow.
5. *Optional:* Obtain actual Ruby Red grapefruit or photos of mutagenesis-derived crops.

Procedure

1. Present the focus question and engage students with a real-world hook *(e.g., "What if I told you that your breakfast grapefruit was created using radiation?")*.
2. Briefly review or introduce DNA structure and the flow of genetic information.
3. Explain that students will model how mutations work at the molecular level.
4. Guide students through examining the original and mutated DNA sequences. Have them identify the specific change (TGC → CAG in top strand).
5. Model transcription for the class, emphasizing base pairing rules and that mRNA uses U instead of T. Students transcribe both sequences.
6. Demonstrate how to use the codon chart with the first codon as a class. Students complete translation for both sequences.
7. Circulate to check that students correctly transcribe and translate both sequences.
8. Lead discussion using guiding questions:
   - *"Which amino acid changed?"* (Threonine → Valine)
   - *"Will this change the protein? Why?"* (Yes, different amino acid = different properties)
   - *"Could this be beneficial, harmful, or neutral?"* (Depends on context)
9. Connect to real examples: Some mutations create disease resistance; some create new colors; some may have no effect.

Day 2

10. Students research in small groups (2–4 students).
11. Assign different crop categories to different groups (grains, fruits, vegetables, ornamentals).
12. Students identify 2–3 specific examples and document: crop name, trait gained, benefit to humans.
13. Encourage students to find images and specific details.
14. Groups share 1–2 key examples.
15. Have class create a collective list of mutagenesis-derived foods.
16. Discuss: *"Are these GMOs?"* (No; no genes inserted from other species.)
17. Address ethical considerations and compare to traditional breeding.

Differentiation

Other ways to connect with students with various needs:

- **Local community:**
  - Invite a plant breeder, agricultural scientist, or extension agent to discuss crop development using various techniques: selective breeding, hybridization, mutagenesis, and genetic engineering.
  - Students may be assigned to photograph and document products in local stores that originated from mutagenesis.
  - Plant and compare heirloom vs. mutagenesis-derived varieties (if growing season permits).
- **Students with special needs:**
  - Language learners: Use color-coding for DNA → RNA → protein steps; pair with language-proficient partners; offer sentence stems for discussion responses.

    - Reading support: Pre-teach vocabulary with visual supports; provide audio recordings of background text; use graphic organizers for research notes; simplify research task to finding one example instead of multiple examples.
    - Auditory learners: Use verbal explanations with visual demonstrations; encourage students to read DNA sequences aloud; provide video resources showing transcription/translation.
    - Visual learners: Use color-coded DNA strands (different colors for each strand) and be aware of color-blindness issues; provide flowcharts of transcription/translation process; show animations of protein synthesis; display physical models of DNA.
- **Extra support:**
    - Meet with small group before lesson to introduce vocabulary and concepts.
    - Show Amoeba Sisters' "Protein Synthesis" **youtu.be/oefAI2x2CQM** or "DNA, Hot Pockets, & The Longest Word Ever: Crash Course Biology #11" **youtu.be/itsb2SqR-R0**
    - Provide partially completed transcription/translation with blanks to fill in.
    - Provide written instructions with checkboxes for each part of the activity.
    - Strategically pair with peer mentors.
- **Extensions:**
    - Protein structure: Students may investigate the differences in r-groups of various amino acids and use protein folding rules to hypothesize what differences in protein structure substituting one amino acid might make.
    - Reverse engineering: Given an amino acid sequence change, work backwards to determine what DNA mutation caused it.
    - Codon wobble investigation: Research why some nucleotide changes don't affect the amino acid (synonymous mutations).
    - Design your own mutation: Choose a trait they'd like to improve in a crop and hypothesize what protein change might create it.
    - Frameshift mutations: Model what happens when a nucleotide is inserted or deleted (not just substituted).
    - Comparison chart: Create a Venn diagram comparing mutagenesis, traditional breeding, and genetic engineering.
    - Ethics debate: Research and debate the safety and ethics of mutagenesis vs. genetic engineering.
    - Historical research: Investigate the history of mutation breeding and key scientists (Hermann Muller, etc.).
    - Mathematical analysis: Calculate the probability of beneficial mutations and why thousands of mutants must be screened.

Student handout

2. It becomes mutated through a site-directed mutagenesis from irradiation with ionizing radiation found in nature. Only one codon is changed.

   Mutated double-stranded DNA
   AGT CCA GTA CAG CCT GAT
   TCA GGT CAT GTC GGA CTA

3. Transcribe both the original and mutated *top* DNA strands into mRNA.

Original: UCA GGU CAU ACG GGA CUA (These are the transcribed mRNA strands.)
Mutated: UCA GGU CAU GUC GGA CUA

4. Use the provided codon chart to translate both of your mRNA strands into an amino acid sequence.

Original: Serine, Glycine, Histidine, Threonine, Glycine, Leucine
Mutated: Serine, Glycine, Histidine, Valine, Glycine, Leucine

5. What is different about your two sequences? Will the protein that they code for be the same? Why or why not? What ramifications could this have for the organism? Could it be positive or will it always be negative since it is a mutation?

Threonine in the original amino acid chain becomes valine in the mutated strain.
It may or may not make a difference, depending on the final structure of the protein. It might affect a phenotype that is observable, or a genotype that is not visible, but could make a change to a protein produced within the organism.
It is not necessarily negative as some mutations are beneficial.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Accurately transcribes DNA to mRNA and translates mRNA to amino acids	Transcription or translation contains multiple errors. Model incomplete.	Transcription and translation explanation is mostly correct, with minor errors.	Transcription and translation are fully accurate. All base pairing rules followed.
Explains how DNA sequence determines traits	Shows minimal understanding of DNA-to-protein connection.	Demonstrates basic understanding that DNA codes for proteins that affect traits.	Articulates clear sequence of events from DNA to RNA to protein to trait with specific examples.
Connects mutagenesis to agricultural innovation	Limited or no connection to food development examples.	Identifies 1–2 mutagenesis crops with basic information.	Provides detailed examples of mutagenesis crops with specific traits and benefits. Synthesizes information.

Rubric for self-assessment

Skill	Yes	No	Unsure
I can explain what happens during transcription (DNA → RNA).			
I can explain what happens during translation (RNA → protein).			
I can use a codon chart to determine which amino acids are coded by mRNA.			
I understand how a change in DNA can change the protein that is made.			
I can explain how mutations can lead to new traits in organisms.			
I can give examples of foods developed through mutagenesis.			
I understand the difference between natural and induced mutagenesis.			