6.8: Biotechnology

Please Pass the Potatoes

You might want to pass on the potato plants pictured below on the right. They are infected with a virus, which is quickly killing them. The potato plants on the left are healthy and productive. Why aren’t they infected with the same virus? The plants on the left have been engineered genetically, using methods of biotechnology, to make them resistant to the virus.

![Image of healthy and infected potato plants]

Figure \(\PageIndex{1}\): (CC BY 3.0; SIRO via [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:Potato_infection1.png))

What Is Biotechnology?

**Biotechnology** is the use of technology to change the genetic makeup of living things for human purposes. Generally, the goal of biotechnology is to modify organisms so they are more useful to humans. For example, biotechnology may
be used to create crops that yield more food or resist insect pests or viruses, such as the virus-resistant potatoes pictured above. Research is also underway to use biotechnology to cure human genetic disorders with gene therapy.

**Biotechnology Methods**

Biotechnology uses a variety of techniques to achieve its aims. Two commonly used techniques are gene cloning and the polymerase chain reaction.

**Gene Cloning**

**Gene cloning** is the process of isolating and making copies of a gene. This is useful for many purposes. For example, gene cloning might be used to isolate and make copies of a normal gene for gene therapy. Gene cloning involves four steps: isolation, ligation, transformation, and selection.

1. In the isolation step, a **restriction enzyme** is used to break DNA at a specific base sequence. This is done to isolate a gene. Restriction enzymes are mostly isolated from bacteria and they only cut DNA at a specific sequence in the DNA. That particular site is called the restriction site of that particular enzyme.

2. During ligation, the enzyme DNA Ligase combines the isolated gene with plasmid DNA from bacteria. (Plasmid DNA is circular DNA that is not part of a chromosome and can replicate independently.) Ligation is illustrated in the figure below. The DNA that results is called **recombinant DNA**.

3. In transformation, the recombinant DNA is inserted into a living cell, usually a bacterial cell. Changing an organism in this way is called **genetic engineering**.

4. Selection involves growing transformed bacteria to make sure they have the recombinant DNA. This is a necessary step because transformation is not always successful. Only bacteria that contain the recombinant DNA are selected for further use.
**Polymerase Chain Reaction**

The **polymerase chain reaction (PCR)** makes many copies of a gene or other DNA segment. This might be done in order to make large quantities of a gene for genetic testing. PCR involves three steps: denaturing, annealing, and extension. The three steps are illustrated in the figure below. They are repeated many times in a cycle to make large quantities of the gene.

1. **Denaturing** involves heating DNA to break the bonds holding together the two DNA strands. This yields two single strands of DNA.
2. **Annealing** involves cooling the single strands of DNA and mixing them with short DNA segments called primers. Primers have base sequences that are complementary to segments of the single DNA strands. As a result, bonds form between the DNA strands and primers.
3. **Extension** occurs when an enzyme (Taq polymerase or Taq DNA polymerase) adds nucleotides to the primers. This produces new DNA molecules, each incorporating one of the original DNA strands.

![Polymerase chain reaction - PCR](https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/06%3A_DNA_and_...) Figure (\cite{PageIndex{3}}): The Polymerase Chain Reaction. The polymerase chain reaction involves three steps. High temperatures are needed for the process to work. The enzyme Taq polymerase is used in step 3 because it can withstand high temperatures. (CC BY-SA 3.0; Enzoklop via [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:PCR.png))

**Gel Electrophoresis**

**Gel electrophoresis** is an analytical technique used to separate DNA fragments by size and due to the negative charge on DNA. Notice in Figure above that the "gels" are rectangular in shape. The gels are made of a gelatin-like material of either agarose or polyacrylamide. An electric field, with a positive charge applied at one end of the gel, and a negative charge at the other end, forces the fragments to migrate through the gel. DNA molecules migrate from negative to positive charges due to the net negative charge of the phosphate groups in the DNA backbone. Longer molecules migrate more slowly through the gel matrix. After the separation is completed, DNA fragments of different lengths can be visualized using a fluorescent dye specific for DNA, such as ethidium bromide. The resulting stained gel shows bands correspond to DNA molecules of different lengths, which also correspond to different molecular weights. Band size is usually determined by comparison to DNA ladders containing DNA fragments of known length. Gel electrophoresis can also be used to separate RNA molecules and proteins.
Figure \(\PageIndex{4}\)). This is a diagram that illustrates the process of Gel Electrophoresis. Gel electrophoresis is used for DNA fingerprinting and is very useful in crime investigation since every individual has different DNA patterns. DNA can be extracted from any sample of body fluid (i.e. blood, semen, or saliva). DNA is mixed with restriction enzymes and amplified with PCR. The mixture of DNA fragment plus restriction enzyme is added into the wells of the agarose gel, which leads to a physical change instead of a chemical one. An electric current is applied to the gel from a power source. Negatively charged DNA moves toward the positive side. Larger fragments move slower and are located near the top whereas smaller fragments move faster and are near the bottom. Bands are stained but different shades indicate the amount of DNA each band contains (CC BY-SA 4.0; Jennifer0328 via Wikimedia Commons)

**Uses of Biotechnology**

Methods of biotechnology can be used for many practical purposes. They are used widely in both medicine and agriculture.

**Applications in Medicine**

In addition to gene therapy for genetic disorders, biotechnology can be used to transform bacteria so they are able to make human proteins. The figure above shows how this is done. Proteins made by the bacteria are injected into people who cannot produce them because of mutations.

Insulin was the first human protein to be produced in this way. Insulin helps cells take up glucose from the blood. People with type 1 diabetes have a mutation in the gene that normally codes for insulin. Without insulin, their blood glucose rises to harmfully high levels. At present, the only treatment for type 1 diabetes is the injection of insulin from outside sources. Until recently, there was no known way to make human insulin outside the human body. The problem was solved by gene cloning. The human insulin gene was cloned and used to transform bacterial cells, which could then produce large quantities of human insulin.
Applications in Agriculture

Biotechnology has been used to create transgenic crops. Transgenic crops are genetically modified with new genes that code for traits useful to humans. The diagram below shows how a transgenic crop is created.

Figure \( \PageIndex{5} \): Creating a Transgenic Crop. A transgenic crop is genetically modified to be more useful to humans. The bacterium transfers the T-DNA (from the Ti plasmid) fragment with the desired gene into the host plant's nuclear genome. A full transgenic plant is grown from a single transformed cell. (CC BY 3.0; Hilarya via 2010.igem.org)

Transgenic crops have been created with a variety of different traits, such as yielding more food, tasting better, surviving drought, tolerating salty soil, and resisting insect pests. Scientists have even created a transgenic purple tomato (pictured below) that contains high levels of cancer-fighting compounds called antioxidants.

Figure \( \PageIndex{6} \): Transgenic Purple Tomatoes: Purple tomatoes are genetically modified to contain high levels of antioxidants. A gene for the compound was transferred into a normal red tomato plant. (Public domain; I'm the author via Wikimedia Commons)

Ethical, Legal, and Social Issues

The use of biotechnology has raised a number of ethical, legal, and social issues. Here are just a few:

- Who owns genetically modified organisms such as bacteria? Can such organisms be patented like inventions?
- Are genetically modified foods safe to eat? Might they have unknown harmful effects on the people who consume them?
- Are genetically engineered crops safe for the environment? Might they harm other organisms or even entire ecosystems?
- Who controls a person's genetic information? What safeguards ensure that the information is kept private?
- How far should we go to ensure that children are free of mutations? Should a pregnancy be ended if the fetus has a
mutation for a serious genetic disorder?

- Can we develop crop species that provide more nutrients and grow in harsher climates? If so, how do we ensure that farmers in impoverished areas have access to these?
- How do we educate the public so they can make well-informed decisions about new technologies?

As a society, we will need to balance the benefits and concerns of new technologies.

Feature: Reliable Sources

Genetically modified foods, or GM foods, are foods produced from genetically modified organisms. These are organisms that have had changes introduced into their DNA using methods of biotechnology. Commercial sale of GM foods began in 1994, with a tomato that had delayed ripening. By 2015, three major crops grown in the U.S. were raised mainly from GM seeds, including field corn, soybeans, and cotton. Many other crops were also raised from GM seeds, ranging from a variety of vegetables to sugar beets. Other sources of GM foods in our diet include meats, eggs, and dairy products from animals that have eaten GM feed, as well as a plethora of food products that contain some form of soy or corn products, such as soybean oil, soybean flour, corn oil, corn starch, and corn syrup. A quick glance at the ingredients list of most processed foods shows that these products are added to many of the items in a typical American diet.

Most scientists think that GM foods are not any riskier to human health than conventional foods. Nonetheless, in many countries, including the U.S., GM foods are given more rigorous evaluations than conventional foods. For example, GM foods are assessed for toxicity, the ability to cause allergic reactions, and the stability of inserted genes. GM crops are also evaluated for possible environmental effects, such as outcrossing, which is the migration of genes from GM plants to conventional crops or wild plant species.

Despite the extra measures used to evaluate GM foods, there is a lot of public concern about them, including whether they are safe to human health, how they are labeled, and their environmental impacts. These concerns are based on a number of factors, such as the worrying belief that scientists are creating entirely new species and a perceived lack of benefits to the consumer of GM foods. People may also doubt the validity of risk assessments, especially with regard to long-term effects. Also, since all the research on safety and usefulness is presented in scientific journals, it can be difficult for the public to be fully informed about the work being done.

Over the past 50 years, there have been many hundreds of studies looking at how these crops affect the environment, the economy, and the health of humans and animals. The results of most of these studies are fairly clear. But, most people don't read the original findings because there are too many and because they can be difficult to understand. The National Academy of Sciences has written a report summarizing the research findings as well as public comments.

They explain the reason for writing the report: "Consumers in the United States and abroad get conflicting information about GE crops. Proponents tout the benefits while opponents emphasize the risks. There was a need for an independent, objective study to examine what had been learned about GE crops, assesses whether initial concerns and promises were realized since their introduction, and investigates new concerns and recent claims."

Summary

- Biotechnology is the use of technology to change the genetic makeup of living things for human purposes.
Biotechnology methods include gene cloning and the polymerase chain reaction. Gene cloning is the process of isolating and making copies of a DNA segment such as a gene. The polymerase chain reaction makes many copies of a gene or other DNA segment.

Gel electrophoresis is a technique that is used to separate DNA of various lengths in a sample. This technique is used in the DNA fingerprinting process of forensic science.

Biotechnology can be used to transform bacteria so they are able to make human proteins, such as insulin. It can also be used to create transgenic crops, such as crops that yield more food or resist insect pests.

Biotechnology has raised a number of ethical, legal, and social issues. For example, are genetically modified foods safe to eat, and who controls a person’s genetic information?

Review

1. Define biotechnology.
2. What is recombinant DNA?
3. Identify the steps of gene cloning.
4. What is the purpose of the polymerase chain reaction?
5. Make a flow chart outlining the steps involved in creating a transgenic crop.
6. Explain how bacteria can be genetically engineered to produce a human protein.
7. Identify an ethical, legal, or social issue raised by biotechnology. State your view on the issue, and develop a logical argument to support your view.
8. Explain what primers are and what they do in PCR.
9. What is gel electrophoresis?
10. True or False. Transgenic crops can be created using recombinant DNA.
11. True or False. Gene cloning is defined as the creation of an identical copy of an entire organism.
12. The enzyme Taq polymerase was originally identified from bacteria that live in very hot environments, such as hot springs. Why does this fact make Taq polymerase particularly useful in PCR reactions?
13. A circular piece of DNA from bacteria that is often used to create recombinant DNA is called a ________ _.
14. In what ways are crops modified genetically? What traits are introduced, and what methods are used to introduce them?
15. What are the main human safety questions about GM foods? How is the human safety of GM foods assessed?
16. What are the main environmental concerns about GM crops? How is a risk assessment for the environment performed?
17. What are the major pros and cons of GM crops and foods? Who is most affected by these pros and cons? For example, for pros, do growers and marketers receive most of the benefits, or do consumers also reap rewards?
18. Which of the following is a possible use of biotechnology, now or in the future?
   A. Curing genetic disorders
   B. Creating transgenic crops that are resistant to pests
   C. Producing human proteins in non-human cells
19. Bacteria that contain a recombinant plasmid are said to be:

A. Transformed
B. Translated
C. Transcripted
D. A transgenic crop

Explore More
https://bio.libretexts.org/link?17036#Explore_More

Learn more about genetic engineering and how it can be applied to science here:

Check out this video describing the use of biotechnology and genetically modified products in the home:
Media, iframe, embed and object tags are not supported inside of a PDF.