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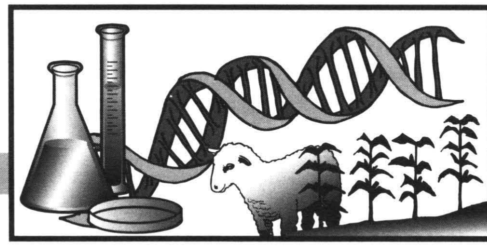


Biotechnology Information

PUBLICATION 443-001

The Science of Biotechnology

*Randy Vines**

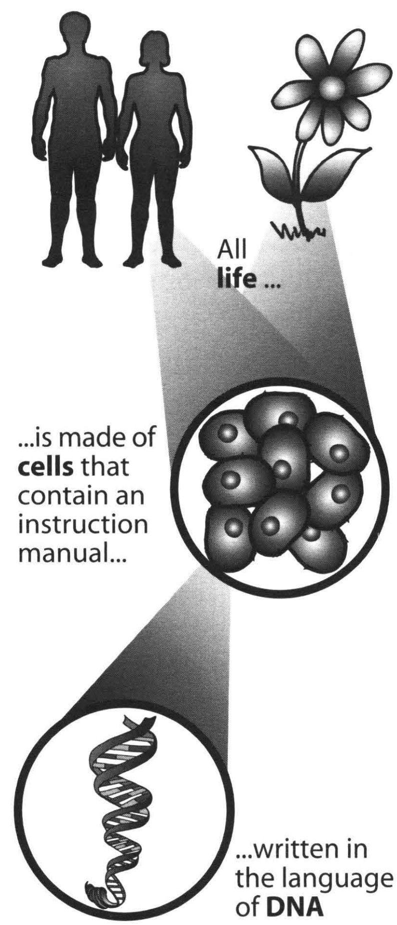
Biotechnology

Understanding the science of biotechnology is helpful in making informed decisions and personal choices related to products derived from its use. The purpose of this publication is to provide an introduction to the basic scientific principles of biotechnology and its applications.

Baking bread, making beer and wine, selectively breeding for desired traits in plants and animals, and using antibiotics and vaccines to fight disease are all examples of traditional forms of biotechnology.

Even though elements of biotechnology have been used for over 10,000 years, the term wasn't coined until 1917, when it was defined as "using organisms or their products for commercial purposes."

Advances in scientific discovery and laboratory techniques during the last half of the twentieth century were significant. They resulted in an updated definition of biotechnology that reflects the ability to modify the deoxyribonucleic acid (DNA) in organisms to produce new products and technologies for human use. The ability to manipulate DNA was first reported in 1973. By today's standards, it was a simple experiment in which a segment of bacterial DNA was cut, "pasted" back together, and then placed into another bacterium. The original work with bacterial DNA has evolved into a library of techniques that are also being used in plants and animals. These advanced techniques have surpassed traditional biotechnology methods and have brought about countless new opportunities in medicine, agriculture, and industry.



The Basics of Life

To understand modern biotechnology, it is necessary to review the basic components and functions of living organisms. A cell is the basic unit of life. Every living organism is made of cells. For example, bacteria and yeast are single-celled organisms, while more complex organisms like plants and animals are made of thousands of cells all working together. It is estimated that humans have over 100 trillion cells! So, if everything alive is made of cells, why then is a blade of grass different from the horse that eats it? It's because they each contain a different set of instructions for life.

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The Genome – a Cell's Instruction Manual

Every cell has a complete "instruction manual" called a genome (pronounced "JEE–nōm"). The genome is inherited from the parent(s) of the organism whether it is a bacterium, plant, or animal. It is the genome that dictates the form and function of an organism. The genome is packaged by the cell to form structures called chromosomes. The chromosomes contain genes, which serve as the "words" of the instruction manual. It is the genes that actually give a cell its specific characteristics.

The Universal Language of DNA

A gene (word) is written using a four-letter alphabet A, C, G, and T, which are abbreviations for the chemicals adenine, cytosine, guanine, and thymine, respectively. These chemicals are called "bases" and together make up DNA. Just as words vary in length, so do genes. A gene usually has between 1,000 and 100,000 A, C, G, and T's in different orders or sequences.

It is important to realize that the four chemical bases of DNA are exactly the same in all living organisms. DNA bases from a rose bush are just like DNA bases from a whale; what differs is the genes that are made using the bases. The universal nature of DNA means that a gene from one organism can function in any other organism. This is a fundamental principle used in modern biotechnology.

Also, it is important to point out that because DNA is present in all living things, humans eat DNA every day! That's right, the carrots, potatoes, fish, and chicken on the dinner table all contain miles of DNA.

One Gene = One Protein = One Cellular Function

The genes found in the cell's instruction manual make it unique, but what is it that genes do? A gene is "read" by the cell and directs the cell to make a specific protein. It is the proteins that control all of the activities of a cell. Proteins give the cell its shape, provide the means to send messages within the cell and to communicate with other cells, fight invaders, make blood and cause it to clot, and the list goes on and on. Researchers are discovering that humans may produce more than 35,000 different proteins!

Traditional versus Modern Uses of Biotechnology

Traditional:

Agriculture/Food
- Selective breeding in animals to obtain a desired trait
- Bread, beer, yogurt, cheese production - using yeast and bacteria
- Hybrid strains of corn that have improved production characteristics

Human health
- Using penicillin (which is derived from a fungus) to fight bacterial infection

Modern:

Agriculture/Food
- Insect and herbicide resistant crops
- Delayed ripening of fruits and vegetables
- Healthier cooking oils from soybeans

Human health
- Discovery of why certain cancers occur – leading to new, specific treatments

Alphabet Analogy of DNA/genome

Instruction manual = Genome

Words = Genes (resulting in proteins)

Language = DNA

Letters in DNA language = A, C, G, T

That's a lot of DNA!

Number of bases (A,C,G,T's) and length of DNA in humans:
- 3 billion bases in human genome – every cell carries all 3 billion bases
- 1 human chromosome contains about 2 inches of DNA
- 1 human cell has 46 chromosomes which together contain about 6 feet of DNA
- 1 human body has ~10-20 billion miles of DNA (enough DNA to stretch to the moon about 40,000 times or wrap around the earth at the equator about 400,000 times)

Terms commonly associated with BIOTECHNOLOGY

genetic engineering

genetically modified organism

recombinant DNA

transgenic organism

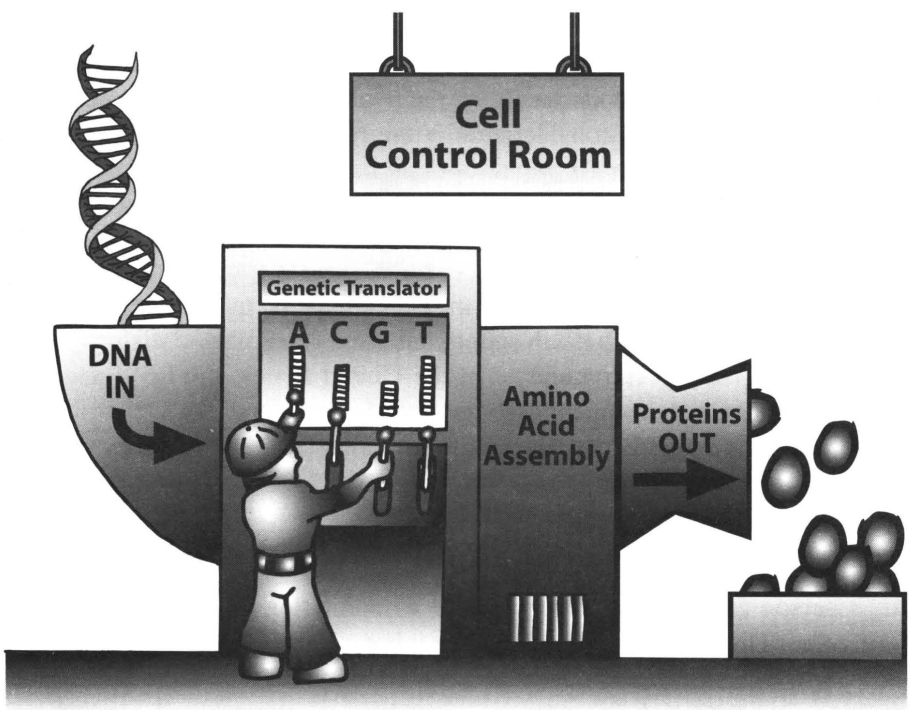
Proteins are made from amino acids that are put together like links in a chain. Humans must eat protein-rich foods everyday to get a daily supply of amino acids. Once ingested, food proteins are broken down in the stomach and the amino acids are absorbed and reused to make new proteins.

A cell can only make a protein if it has the correct gene or word in its instruction manual. Because genes make up the genome, if an organism produces 10,000 different proteins, then its genome will have 10,000 different genes. This means that genomes vary in size depending on the number of proteins that must be produced. Genomes can also contain a lot of DNA that is not part of a gene; scientists are currently trying to figure out why. Bacteria have millions of letters (A, C, G, T bases of DNA) in their genomes, while humans have around 3 billion. Just imagine the daunting task of mapping the human genome.

Controlling Protein Production

A cell can't keep a supply of 35,000 different proteins sitting around until it needs them, so how does a cell know when and what proteins to make? The "reading" or expression of a gene is like a light that is controlled by a switch. Genes can be "on" or "off" as determined by which proteins the cell requires at any given time. In this way, the cell only makes proteins that it needs.

Control of gene expression is also the reason that heart cells differ from brain cells, which differ from skin cells, and so on. Cells throughout the body receive signals from specific proteins that let them know which genes to express. Even though every cell contains the entire genome for an organism, each cell only expresses some of its genes. This gives each cell unique properties by virtue of the proteins it makes.



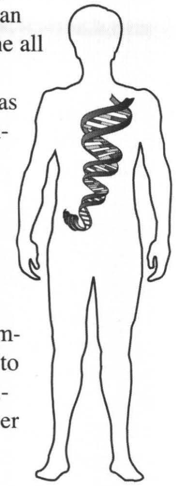
Conceptual illustration of protein production within a cell.

A New Era

Following the first experiment with DNA manipulation in 1973, scientists quickly became more skilled at modifying genes and moving pieces of DNA so that today they have what can be described as a "recombinant DNA technology toolbox."

What is the "Human Genome Project?"

- The goal of the human genome project is to determine the sequence of all the DNA within a human cell
- There are about 3 billion bases of DNA
- By knowing the sequence of the DNA, researchers can identify and examine all of the genes.
- Until this project was completed, the number of genes in humans was estimated to be 100,000. Based on preliminary results from the Genome Project, the true number of genes seems to be less. Recent estimates put the number of genes at about 35,000.
- The function of many of the proteins encoded by these genes is unknown. However, scientists can compare the human proteins to what is known about similar proteins in other organisms.
- This may help find the basis for diseases and aid in designing new treatments as well as explain why humans are unique.



How biotechnology has advanced insulin production for diabetics

1920 – 1980's

- Insulin was purified from pig pancreas and injected into diabetics
- **Problems:**
  - Allergic reactions to pig insulin occurred in some diabetics
  - Insulin administered by injection

1980's – Now

- Human gene for insulin inserted into bacteria – human insulin protein purified from bacteria – allergic reactions no longer occur
- **Problem:** Insulin is still administered by injection

On the horizon

- Inhaled human insulin may alleviate the need for injections

How biotechnology may impact the world

Human health is the main focus of biotechnology today.

Recent highlights include:

- New ways to fight certain cancers through treatment with specialized proteins that were engineered at the DNA level to recognize and stop tumor cell growth.
- Identification of defective genes that may be the cause of diseases such as cystic fibrosis and childhood deafness.
- New methods to immunize people against disease by eating fruits and vegetables that have been genetically engineered to contain the vaccine or simply by wearing a patch on the skin to deliver the vaccine (like the patches used to overcome nicotine addiction). These types of vaccines could be inexpensive, need no refrigeration, and be administered without needles and specialized healthcare workers, each of which is a major barrier to the effective use of vaccines around the world.

Agriculture is the second largest focus of biotechnology efforts and can also improve human health.

Some of the latest developments include:

- "Golden rice," a rice which has been genetically engineered to give people more Vitamin A, could help prevent millions of cases of blindness and death worldwide.
- Soybeans that yield healthier, reduced saturated fat oils, lowering blood cholesterol levels.
- Crops that are able to withstand pests and environmental stresses such as heat, cold, drought, and high concentrations of salt in soil and water.

Biotechnology is also proving its worth in other diverse ways:

- Researchers are working to generate peanuts and milk that lack the genes for the proteins that causes allergic reactions in some people, permitting allergy sufferers to eat them.
- In mining operations, microorganisms are being used to recover precious metals from soils previously deemed unprofitable.
- Bacteria have been genetically engineered to produce indigo, a costly dye used to make blue jeans.

Now it is routine to use genetic engineering to move entire genes (1000s of bases of DNA) between bacteria, plants, insects, and animals, resulting in transgenic organisms. Scientists have learned how to "flip" the switch that controls gene expression and protein production. This allows them to stop production of a protein altogether or regulate exactly when a protein is produced in an organism. Additionally, it is now possible to restrict where in an organism a gene is expressed. For example, new proteins can be produced in the milk of a cow and nowhere else in its body. This use of a cow as a "manufacturing plant" is being tested by the pharmaceutical industry as a way to produce large quantities of life-saving drugs that would otherwise be impractical because of limited availability and cost.

All of these methods of working with DNA and proteins have furthered the goals of traditional biotechnology. The traditional practice of selective breeding for a specific trait can now be done more quickly and without the potential manifestation of undesirable traits. Studying individual genes that might be defective can identify the cause of a disease and can possibly provide new medicines or cures. Currently over 4,000 human diseases or conditions are linked to genetic disorders.

Challenges Remain

Today's biotechnology is not as straightforward as baking bread or breeding plants and animals for selected traits. As with other technologies that have the potential to fundamentally change the world, the benefits of biotechnology must be weighed against the risks. For example, consider the benefits and risks associated with using cars, nuclear energy, and certain medicines.

Regulation and Safety – Anticipating Unanticipated Effects

One of the biggest concerns of modern biotechnology is that a given product or application may create unforeseen problems. For example, an undesirable result of putting new proteins in foods would be the potential for certain people to have allergic reactions. Another consideration is the natural transfer of new traits to wild populations. For instance, when agricultural crops have been genetically altered to be herbicide-resistant, the gene for the resistance trait could migrate to wild species of plants, which would in turn make them resistant to herbicides.

To make sure such risks are minimized, measures must be taken to identify these problems before they occur through sound, unbiased research and dialogue in the scientific and regulatory community. In the United States, the Food and Drug Administration, the Environmental Protection Agency, and the Department of Agriculture provide regulatory oversight to biotechnology research, product development, and approval.

Ethical Implications

Telling a person that they are going to have a debilitating disease later in life by analyzing their DNA may be possible, but is it beneficial if there is no way to prevent it? Should insurance companies be allowed to look at a person's DNA analysis to determine their risk for disease – just like checking blood pressure and asking if they smoke cigarettes? Is there something morally wrong with certain products or technologies? Questions like these will certainly have to be addressed as more advances are made in the field of biotechnology.