Publisher's Note

Salem Press is pleased to add *Principles of Biotechnology* as the ninth title in the *Principles of* series that includes *Chemistry*, *Physics*, *Astronomy*, *Computer Science*, *Physical Science*, *Biology*, and *Scientific Research*. This new resource introduces students and researchers to the fundamentals of biotechnology using easy-to-understand language that gives readers a solid start and deeper understanding and appreciation of this complex subject.

- The 134 articles include 109 entries that explain basic principles of biotechnology, ranging from Alternative energy sources to Zygomycetes, with attention paid to Cloning; Synthetic fuels; Medicinal plants; Stem cell research and technology; Genetically modified organisms; and more. All of the entries are arranged in A to Z order, making it easy to find the topic of interest.
- The volume also features 23 biographies of key figures in biotechnology that include a description of each individual's significant contributions to the field, ranging from David Baltimore to David Norton Zinder.

Entries related to basic principles and concepts include the following:

- Fields of study to illustrate the connections between the topic and the various branches of science related to biotechnology;
- An Abstract that provides brief, concrete summary of the topic and how the entry is organized;
- Text that gives an explanation of the background and significance of the topic to biotechnology as well as describing the way a process works, how a procedure or technique is applied to achieve important goals related to the environment, health, nutrition, industry, and agriculture.
- Illustrations that clarify difficult concepts via models, diagrams, and charts of such key topics as biomechanical engineering and DNA fingerprinting;
- Further reading lists that relate to the entry.

Entries related to important figures in biotechnology include the following:

- A brief overview of the individual and his or her contributions;
- Key dates and biographical data;
- Primary field(s) and specialties;
- Sidebars explaining the individual's significant advances, inventions, or discoveries;
- Text that provides information about the scientist's Early Life, Life's Work, and Impact;
- Further reading lists that relate to the entry.

This reference work begins with a comprehensive introduction to the field, written by volume editor Christina A. Crawford, Assistant Director for Science and Engineering at the Rice Office of STEM Engagement (R-STEM) at Rice University in Houston, Texas.

The book includes helpful appendixes as another valuable resource, including the following:

- Time Line of Inventions and Scientific Advancements in Biotechnology
- Glossary;
- General Bibliography; and
- Subject Index.

Salem Press and Grey House Publishing extend their appreciation to all involved in the development and production of this work. The entries have been written by experts in the field. Their names and affiliations follow the Editor's Introduction.

Principles of Biotechnology, as well as all Salem Press reference books, is available in print and as an e-book. Please visit www.salempress.com for more information.

Editor's Introduction

It's Monday, around 6 p.m., and like any other night, it is time to sit down and have dinner. This simple event happens every night for millions of people around the world with such consistency and regularity that it is often taken for granted. One out of every eight people, about 795 million worldwide, however, is malnourished, meaning that he or she does not have enough food to maintain his or her health and be active. As of 2016, that number represented about 12.9 percent of the world's population. Making food more accessible to everyone in the world is a serious concern as populations continue to grow while the land available to produce food to feed those populations stays the same, or even decreases. Many people believe that this issue is one of the many problems facing our globe that can be addressed by means of biotechnology, along with other vital concerns including access to routine medications such as vaccinations or vitamin supplements. For many biotechnologists, the goal is to save the world, one invention at a time.

What is Biotechnology?

Biotechnology is defined as the use of living organisms, or substances obtained from living organisms, to produce products or processes of value to humankind.

While it is true that biotechnology has made tremendous advances in the areas of human and veterinary medicine, agriculture, food production, and other fields, these advances have also raised some genuine concerns about how biotechnology should be monitored. Ongoing debates continue the effort to balance the potential of biotechnology, in particular genetic engineering, and its ability to produce organisms that may benefit humans, against growing concerns about the potential for these advances and inventions to disrupt ecosystems, negatively affect human health, or be used in ethically inappropriate ways.

Many countries have different interpretations of the field. Australia, for example, defines biotechnology as any technological application that uses biological systems, including living organisms or derivatives thereof, to make or modify products or processes for specific use. Canada defines biotechnology as the application of science and engineering to the direct or indirect use of living organisms, or parts or products taken from living organisms, in their natural forms.

In the United States, an entity, whether a research facility or a business, is considered as working in the field of biotechnology if any of the following types of research take place:

- **Researching the coding or sequencing of DNA**: Genomics, pharmacogenetics, gene probes, DNA sequencing/synthesis/amplification, genetic engineering.
- **Researching proteins and other biomolecules**: Protein/peptide, sequencing/synthesis, lipid/protein glycoengineering, proteomics, hormones and growth factors cell receptors/signaling/pheromones.
- **Researching cell and tissue culture and engineering**: Cell/tissue culture, tissue engineering, hybridization, cellular fusion, vaccine/immune stimulants, embryo manipulation.
- **Researching process biotechnologies**: Bioreactors, fermentation, bioprocessing, bioleaching, bio-pulping, bio-bleaching, biodesulphurization, bioremediation, and biofiltration.
- **Researching subcellular organisms**: Gene therapy, viral vectors.

Each of the research areas above can be studied in any of the various fields of biotechnology.

Branches of Biotechnology

Researchers who study biotechnology generally organize themselves among five different branches of biotechnology: animal, bioinformatics, environmental, medical, and industrial.

- **Animal biotechnology**: This branch of biotechnology deals with the development of transgenic animals. The research is focused in areas such as the increase of milk or meat production with high resistance to various diseases. It also deals with in vitro fertilization of an egg and the transfer of an embryo to the womb of female animal for further development.
- **Bioinformatics**: Bioinformatics is a branch of biotechnology that is a combination of both computer science and biotechnology.

Bioinformatics helps us to develop tools to analyze data related to biotechnology. Bioinformatics is used in various research studies aimed at goals such as the development of new and more effective medicines. It is also used to increase the fertility of plants and to provide them with a defense against pest, drought and diseases. Bioinformatics is vital in a number of areas that are key contributors to biotechnology and the pharmaceutical sector.

- **Environmental biotechnology**: This branch of biotechnology is dedicated to promoting a healthy environment. With the help of the process called micropropagation (a practice of producing larger number of plants through the existing stock of plants), scientists are better able to select the right quality of plants and crops for specific growing conditions and environments. Transgenic plants (plants whose DNA is modified) can also be designed to grow in a specified environment with the help of certain chemicals.
- **Medical biotechnology**: This branch of biotechnology focuses on improving the health of humans and animals by developing the technology necessary to produce medicines. It also helps to create or design organisms meant to more effectively treat diseases and conditions. Through the process of genetic manipulation, it can be used to cure genetic issues in organisms. Medical biotechnologists research diseases in organisms in order to develop new ways to achieve an accurate diagnosis through the use of more accurate testing protocols. Stem cell therapy is one area that continues to show great potential to either generate new organs or repair the damaged tissues in organisms.
- **Industrial biotechnology**: This kind of biotechnology is used and applied in various industries and their processes. The development of biopolymer (plastics) substitutes has allowed the automobile industry to invent improved parts and fuels for the vehicles of the future. The creation of "high-tech" fibers has had an impact on the clothing industry as well as the sports and fitness sectors. There may be other broad impacts across all industries, from energy to entertainment, as industrial biotechnology develops new chemicals and production processes.

Stepping Stones in Biotechnology

The term biotechnology itself is relatively new, but the practice of biotechnology is as old as civilization. In fact, it played a key role in the initial development of societies and civilizations, since they could only start to evolve once humans learned to apply selective breeding techniques–a basic biotechnological skill–to improve and increase the food crops they grew and livestock they raised.

Artificial insemination, the process in which semen is collected from the male animal and deposited into the female reproductive tract through artificial techniques rather than natural mating, emerged as a practical procedure roughly a century ago, although as early as 1784, Italian biologist Lazzaro Spallanzani successfully inseminated a dog.

While genetic engineering is often considered a phenomenon of the late twentieth century, the building blocks for such technology began with the first isolation of DNA in 1869 and the subsequent awareness of its relevance to heredity starting in 1928. The first accurate double-helix model of DNA was developed in 1953 by James D. Watson and Francis Crick, and the first gene sequence and recombinant DNA was created in 1972 by researchers from Stanford University. The latter discovery truly heralded the beginning of the biotechnological industry and the development of genetically modified organisms (GMOs).

In 1963, Margaret Oakley Dayhoff, an American physical chemist and a major figure in the evolving science of bioinformatics, began compiling protein sequences into a series of books titled *Atlas of Protein Structure and Function*. By 1978, however, the *Atlas of Protein Structure and Function* had grown too large and cumbersome to permit comparisons and analyses to be easily performed. Her second major contribution was to create a database infrastructure to convert the atlas to the first online biological database, making it accessible to researchers who used it to sort, manipulate, and align multiple protein sequences. The database developed by Dr. Dayhoff and her successors, Dr. Winona Barker and Dr. Robert Ledley, became know as the Protein Information Resource (PIR). In 2002 PIR, along with its international partners, EBI (European Bioinformatics Institute) and SIB (Swiss Institute of Bioinformatics), were awarded a grant from NIH to create UniProt, a single worldwide database of protein sequence and function.

Biotechnology has played a significant role in treating serious medical conditions, including diabetes. The first effective treatment called for the extraction of insulin from cattle and pigs and while it saved millions of lives, it wasn't perfect, as it caused allergic reactions in many patients. The first recombinant DNA-produced synthetic "human" insulin was produced in 1978 using *E. coli* bacteria to produce the insulin. Eli Lilly went on in 1982 to sell the first commercially available biosynthetic human insulin under the brand name Humulin. Genetic engineering has also been used to synthesize protropin, a human growth hormone (HGH) employed in the treatment of growth failure conditions such as hyposomatotropism.

Biotechnology has played an important role in helping to effectively remediate environmental disasters. In March, 1989, the Exxon Valdez oil tanker spilled millions of gallons of crude oil in Prince William Sound, Alaska. On many beaches, the Environmental Protection Agency authorized the use of simple bioremediation techniques, such as stimulating the growth of indigenous oil-degrading bacteria by adding common inorganic fertilizers. Beaches cleaned by this method did as well as beaches cleaned by mechanical methods. In another instance of successful bioremediation, selenium-contaminated soil in the Kesterson National Wildlife Refuge in California was partially decontaminated in the 1980s through the method of supplying indigenous fungi with organic substrates such as casein and waste orange peels. This promoted as much as 60 percent selenium volatilization in less than two months.

The cloning of Dolly the sheep in Scotland in 1996 opened a whole new avenue in the use of biotechnology for livestock production. The use of cloning technology in conjunction with surrogate mothers provides the means to produce a whole herd of genetically superior animals in a short period of time. As well as offering a new way to raise livestock, it also brought serious questions about the ethics of cloning and genetic engineering to the forefront of a public debate that continues to this day.

Current Advances in Biotechnology

Over the past few years there have been many advances in the field of biotechnology that border on the realm of science fiction. From cloned animals to nerve regeneration, this field appears to be limited only by the imagination of the scientist working within it. Cloning, for example, was a subject only talked about in science fictions books and movies. Now, as cloning technologies continue to advance, scientists in South Korea have managed to not only clone a dog, but also change its genetic make-up such that the dog actually glows in the dark.

If you have ever played or been a fan of football, biotechnology is helping there as well. Most football fans are aware of the horrific injuries that happen on the football field. One wrong tackle could cause nerve damage that might impair a player for the rest of his or her life. Now a company called Regenxx is attempting to regenerate damaged nerves by using stem cells in hopes that they can give injured athletes the chance to regain mobility.

Biotechnology is also changing the way we use prescription drugs in America. In 2017, Abilify Mycite became the first smart pill that that has been approved by the Federal Drug Administration (FDA). This smart pill is able to transmit information back to doctors once it has been ingested, giving caretakers vital data on medication regimens of the patient.

Biotechnology breakthroughs are driving advances in far more areas than health care alone; they are improving environmental quality all over the world. Global warming is widely perceived as one of the biggest problems of the twenty-first century, playing a role in widespread climate change that has changed weather patterns, growing conditions, and sea levels. To help combat the problem, many countries are researching ways that biotechnology might make the switch to renewable sources of energy such as biofuels possible. The potential of biofuels made from ethanol and algae as fuels for vehicles may help reduce levels of carbon emissions produced by fossil fuels, thereby reducing or eliminating one of the root causes of global warming. Biofuels are derived primarily from plants, a renewable resource, making them sustainable rather than nonrenewable. As the demand for biofuel has grown, biotechnology has been applied to improve the methods of producing fuel. Biotechnologists have created microorganisms that can ferment biomass materials derived from sugars (sugar cane, sugar beet and molasses), starch (corn, wheat, grains) or cellulose (forest products). They have also learned to modify strains of algae in order to dramatically increase the amount of oil that the algae produce without significantly inhibiting growth.

The fundamental aim of environmental biotechnology is to use organisms to control contamination and treat waste by means of the following four concepts: bioremediation; prevention; detection and monitoring; and genetic engineering. The use of biotechnology in the treatment of waste and pollution control is not a new idea. For more than a century, many communities have relied on natural processes and microbes to break down and treat sewage. In the process called bioremediation, microorganisms including fungi and bacteria along with their enzymes are used to return a contaminated environment to its original condition. Naturally occurring biological degradation processes are purposely employed to remove contaminants from areas where they have been released. The use of such processes requires a solid scientific understanding of the contaminant, its impact, and the affected ecosystem. The aim of environmental biotechnology is to provide a natural approach to tackling environmental issues that begins with the identification of biohazards—determining which contaminants are present, for how long, and in what quantity— and concludes with the successful restoration of industrial, agricultural, and natural areas that have been affected by contamination.

With the help of two promising gene editing tools—Cluster Regularly Interspaced Short Palindromic Repeats (CRISPR) and the RNA-guided DNA endonuclease enzyme Cas9—scientists are hoping to change the world, especially for people born with a genetic disorder. CRISPR-Cas9 is fast and inexpensive, as well as being the most accurate technique for editing DNA thus far. This unique technology allows scientists to edit a person's DNA sequence by removing, adding, or altering sections of the sequence. One promising aspect is the potential to cure genetic diseases like sickle cell anemia or more complex diseases including cancer and HIV. In 2016, a Chinese group lead by oncologist Lu You at Sichuan University in Chengdu was the first research team to conduct human trials using CRISPR-Cas9 on immune cells to improve the body's attack against cancerous tissue. In 2017, China announced that there will be over 20 human trials underway by 2018 that will utilize CRISPR-Cas9 as a treatment for conditions ranging from HIV infection, human papillomavirus, and even high blood cholesterol. This is an exciting and thrilling time to be involved with medical biotechnology. It is also one that has started to sound some alarms. Scientists, politicians, and religious leaders are voicing worries about the ethical issues of using a genetic tool of this nature, especially if it is used to edit reproductive cells, which could affect generation after generation of humans.

In this Book

In this book, you will find a collection of biotechnology articles that explain the basics, history, and applications of biotechnology. This volume provides readers with the important information they need to understand the basic concepts, ethical arguments, possibilities, and consequences of biotechnology. The text provides students and researchers with an easy-to-understand introduction to the fundamentals of biotechnology.

——*Christina A. Crawford, MS Ed*

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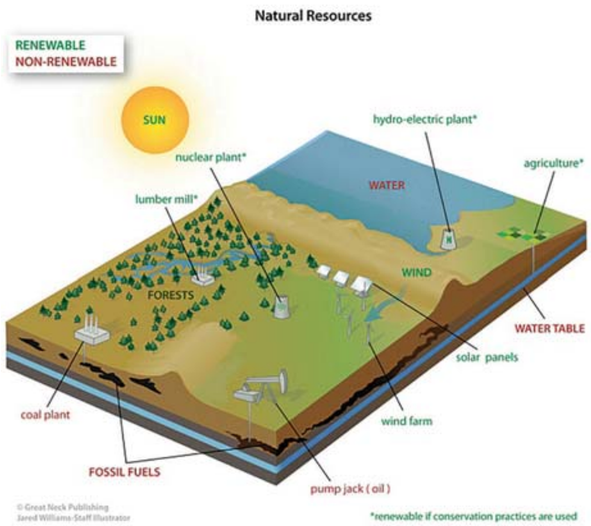
A

Alternative energy sources



Natural Resources: The earth has many natural resources, some are renewable and others are not. Conservation practices will ensure that resources do not become depleted.
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FIELDS OF STUDY

Biochemistry; Biotechnology; Molecular biology; Chemical engineering; Industrial biotechnology (or White biotechnology)

ABSTRACT

Energy sources that offer alternatives to the burning of fossil fuels such as coal and petroleum are urgently needed to address rising demand for energy in ways that will not contribute to air pollution and climate change. The ideal alternative energy source is renewable or inexhaustible and causes no lasting environmental damage.

BACKGROUND

Both the extraction and the burning of fossil fuels have caused severe and growing damage to the environment, contributing to such problems as air pollution, the release of greenhouse gases (which retain heat and contribute to climate change), and sulfuric acid in rainfall. Nuclear energy sources are very limited in supply and expensive, require extreme amounts of processing, and produce long-lasting radioactive waste. In the long term, energy release from nuclear fusion has been proposed as a limitless supply of power, but industrial-scale production of fusion power continues to pose large and uncertain obstacles and hazards.

Alternative Sources

Solar Power. The sun powers winds, ocean currents, rain, and all biomass growth on the earth's surface. Because the availability and extraction means for each of these secondary sources of solar power are diverse, each forms a different field of alternative energy technology. Where solar power is extracted and converted to energy directly, the capture can be by means of flat-plate receivers that collect at the incident intensity but can operate in diffuse light, or by means of concentrators that can achieve intensities of several hundred suns but work poorly in diffuse light.

In solar photovoltaic power (PV) technology, solar radiation is directly converted to useful power through PV cell arrays, which require semiconductor mass-production plants. PV cell technologies have evolved from using single-crystal silicon to using thinner polycrystalline silicon, gallium arsenide, thin-film amorphous silicon, cadmium telluride, and copper indium selenide. The needed materials are believed to be abundant enough to meet projected global growth. The process of purifying silicon requires large inputs of energy, however, and it generates toxic chemical waste. Regeneration of the energy required to manufacture a solar cell requires about three years of productive cell operation.

Solar cell technology continues to evolve. Broadband solar cell technologies have the potential to make cells sensitive to as much as 80 percent of the energy in the solar spectrum, up from about 60 percent. High-intensity solar cells could enable operation at several hundred times the intensity of sunlight, reducing the cell area required when used with concentrator mirrors and enabling high thermal efficiency.

Direct solar conversion is another option. Laboratory tests have shown 39 percent conversion from broadband sunlight to infrared laser beams using neodymium-chromium fiber lasers. Direct conversion of broadband sunlight to alternating-current electricity or beamed power through the use of optical antennae is projected to achieve 80 to 90 percent conversion. Such technologies offer hope for broadband solar power to be converted to narrowband power in space and then beamed to the earth by satellites.

Another way of harnessing solar power is through solar thermal technology. Solar concentrators are used with focal-point towers to achieve temperatures of thousands of kelvins and high thermal efficiency, limited by containment materials. The resulting high-temperature electrolysis of water vapor generates hydrogen and oxygen in an efficient manner, and this technology has demonstrated direct solar decomposition of carbon dioxide (CO_2) to carbon monoxide (CO) and oxygen.

Wind Power. Winds are driven by temperature and pressure gradients, ultimately caused by solar heating. Wind energy is typically extracted through the operation of turbines. Power extraction is proportional to the cube of wind speed, but wind-generated forces are proportional to the square of wind speed. Wind turbines thus can operate safely only within a limited range of wind speed, and most of the power generation occurs during periods of moderately strong winds. Turbine efficiency is strongly dependent on turbine size and is limited by material strength. The largest wind turbines have reached 8 megawatts in capacity. Denmark, the Netherlands, and India have established large wind turbine farms on flat coastal land, and Germany and the United Kingdom have opted for large offshore wind farms. In the United States, wind farms are found in the Dakotas, Minnesota, and California, as well as on Colorado and New Mexico Mountain slopes and off the coasts of Texas and Massachusetts.

Because of wind fluctuations and the cubic power relation, wind power is highly unsteady, and means must be established for storing and diverting the power generated before it is connected to a power grid. In addition, offshore and coastal wind farms must plan for severe storms. Smaller wind turbines are sometimes used for power generation on farms and even for some private homes in open areas, but these tend to be inefficient and have high installation costs per unit power. They are mainly useful for pumping irrigation water or for charging small electrical devices.

Environmentalists have raised some concerns about large wind turbines. The machinery on wind farms causes objectionable noise levels, and many assert that the wind turbine towers themselves constitute a form of visual pollution. Disturbances to wildlife, particularly deaths and injuries among bird populations, are another area of concern. In addition, the construction of wind farms often requires the building of roads through previously pristine areas to enable transportation of the turbines' large components.

Hydroelectric Power and Tidal Power. Large dams provide height differences that enable the extraction of power from flowing water using turbines. Hydroelectric power generated by dams forms a substantial percentage of the power resources in several nations with rivers and mountains. However, the building of large dams raises numerous technical, social, and public policy issues, as damming rivers may displace human inhabitants from fertile lands and may result in the flooding of pristine ecosystems, sometimes the habitats of endangered species. Increased incidence of earthquakes has also been associated with the existence of very large dams.

In some of the world's remote communities, micro hydroelectric (or micro hydel) plants provide power, generating electricity in the 1–30 megawatt range. Very small-scale systems, known as pico hydel, extract a few kilowatts from small streams; these can provide viable energy sources for individual homes and small villages, but the extraction technology has to be refined to bring down the cost per unit of power.

Although tidal power is abundant along coastlines, the harnessing of that power has been slow to gain acceptance, in part because of the difficulties of building plants that can survive ocean storms. Tidal power is extracted in two principal ways. In one method, semipermeable barrages are built across estuaries with high tidal ranges, and the water collected in the barrages is emptied through turbines to generate power. In the second, offshore tidal streams and currents are harnessed through the use of underwater equivalents of wind turbines.

Tidal power plants typically use pistons that are driven up and down by alternating water levels or the action of waves on turbines. A rule of thumb is that a tidal range of 7 meters (23 feet) is required to produce enough hydraulic head for economical operation. One drawback is that the 12.5-hour cycle of tidal operation is out of synchronization with daily peak electricity demand times, and hence some local means of storing the power generated is desirable. In many cases, impellers or pistons are used to pump water to high levels for use when power demand is higher.

China, Russia, France, South Korea, Canada, and Northern Ireland all have operational tidal power stations. The first U.S. tidal power station became operational in 2012 in Cobscook Bay, near Eastport, Maine.

Biomass Power. Biomass, which consists of any material that is derived from plant life, is composed primarily of hydrocarbons and water, so it offers several ways of usage in power generation. Combustion of biomass is considered to be carbon-neutral in regard to greenhouse gas emissions, but it may generate smoke particles and other pollution.

One large use of biomass is in the conversion of corn, sugarcane, and other grasses to ethyl alcohol (ethanol) to supplement fossil petroleum fuels. This use is controversial because the energy costs associated with producing and refining ethanol are said to be greater than the savings gained by using such fuel. It is argued that subsidies and other public policies and rising energy prices entice farmers to devote land to the production of ethanol crops, thus triggering shortages and increases in food prices, which hurt the poorest people the most. Brazil has advanced profitable and sustainable use of ethanol extracted from sugarcane to replace a substantial portion of the nation's transportation fossil-fuel use.

Jatropha plants, as well as certain algae that grow on water surfaces, offer sources of biodiesel fuel. Biodiesel from *Jatropha* is used to power operations on several segments of India's railways, and vegetable oil from peanuts and groundnuts, and even from coconuts, has been used in test flights of aircraft ranging from strategic bombers to jetliners.

Biogas and Geothermal Energy. Hydrocarbon gases from decaying vegetation form large underground deposits that have been exploited as sources of energy for many years. Technology similar to that used in extracting energy from these natural deposits, which are not considered a renewable energy source, can be used to tap the smaller but widely distributed emissions of methane-rich waste gases from compost pits and landfills. Creating the necessary infrastructure to capture these gases over large areas poses a difficult engineering challenge, however. In addition, care must be taken to avoid the release of methane from these deposits into the atmosphere, as methane is considered to be twenty times as harmful as carbon dioxide as a greenhouse gas.

Geothermal energy comes from heat released by radioactive decay inside the earth's core, perhaps augmented by gravitational pressure. Where such heat is released gradually through vents in the earth's surface, rather than in volcanic eruptions, it forms an abundant and steady, reliable, long-term source of thermal power. Hot springs and geothermal steam generation are used on a large scale in Iceland, and geothermal power is used in some American communities and military bases.

—*Narayanan M. Komerath and Padma P. Komerath*

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ANIMAL BREEDING

Since the 1940's, dairy cows in the United States, such as these in Sacramento, California, have been intensively bred for milk production, which has tripled since that time. Photo courtesy of USDA NRCS. [Public domain], via Wikimedia Commons

FIELDS OF STUDY

Animal Science; Biology; Genetics; Reproductive technology

ABSTRACT

Animal breeding has been used to produce animals more useful to humankind since animals were first domesticated. Traditionally it involved selecting individual animals for desired traits and mating them, with the intent of producing improved offspring. In the second half of the twentieth century, extensive performance records and computer-aided analysis permitted superior animals to be identified more accurately and, via reproductive technologies, to be utilized more rapidly for improving the major livestock species. In the future, molecular biology and biotechnology promise to expedite this process by identifying desirable genes from the same or different species and incorporating them into domesticated animals. Animal breeding will continue to augment the value of domesticated animals as a renewable resource.

GENETIC INHERITANCE

Animal breeding is predicated on two principles: that the genes of an animal are inherited from its parents and that its genes are an important determinant of its appearance, structure, behavior, and productivity. In animal species, almost all genes are located in the nucleus of an organism's cells; these nuclear genes are inherited from both parents. A few genes, located outside the nucleus in subcellular structures called mitochondria, are derived only from the mother. The full complement of genes, known as the genome, directs the development of an individual animal, the synthesis of all body tissues, including metabolic machinery, and to a large extent the characteristics or traits exhibited. Different forms of genes, referred to as alleles, are responsible for the individuality of living things.

Some characteristics are determined by alleles of one gene—for instance, the absence of horns or the occurrence of a metabolic disease. In such cases a single mutation can lead to a deleterious condition. However, most traits of significance involve alleles of more than one gene. Superior characteristics for growth rate or milk yield, so-called polygenic traits, result from the combination of alleles of many genes. Animal breeding seeks to improve genetically the future population of a particular species by increasing the proportion of desirable alleles or the appropriate combination of such alleles. Genetic improvement requires selection of appropriate breeding animals and a mating plan for such animals.

SELECTION AND MATING SYSTEMS

Selection is the process of determining which animals are to be used as breeding stock. The simplest form of selection considers only traits of the individual, whereas more complex selection takes account of additional information on relatives, such as siblings, parents, and offspring. The accuracy of predicting genetic progress is improved by considering relatives. This process requires reliable measures for desired traits, acquisition of records from numerous animals, and analysis of the records, which has been aided by advances in statistical theory and computational power. The result is a ranking of animals based on their genetic merit for single or multiple traits.

Several systems have been used for mating selected animals. One involves complementarity, whereby individuals with high genetic merit for different traits are mated. It has been used to improve livestock in developing countries by mating animals adapted to local conditions with highly productive ones from developed countries. The beef cattle, swine, and poultry industries make heavy use of crossbreeding, in which animals from different breeds are mated. One of its advantages is the "hybrid vigor" that results. Another system is mating the best to the best. One of its hazards is inbreeding, or the mating of relatives, which often results in decreased fertility and viability.

Environmental Factors

Performance or productivity is determined not only by genetics but also by environmental factors. Climate, nutrition, and management can affect the extent to which the genetic potential of an animal is realized. Because the productivity of an animal can be affected deleteriously by heat and disease, climate and other environmental factors can influence animals' performance. Similarly, the management system used, whether intensive or extensive, can also affect productivity. Accordingly, the most productive animal under one set of conditions may not necessarily be the most productive under another. Interactions between genetics and the environment must be considered in animal breeding.

Post-1940's Developments

Beginning in the mid-twentieth century, reproductive technologies, most notably artificial insemination, contributed to rapid improvement in animal performance. These technologies permit animals with the best genetics to be used widely, resulting in numerous offspring from which to select the best breeding stock for the next generation. As a result of intensive selection and management in the United States beginning in the 1940's, milk production per cow has more than tripled. The growth rate of chickens has more than doubled, as has egg production. Such increases have occurred concurrently with a higher efficiency in raising animals for human food.

Molecular biology and biotechnology hold the potential to alter animal breeding processes significantly in the early twenty-first century. Further understanding of the genomes of livestock species should permit identification of specific genes that will increase the productivity of these animals. One approach, known as marker-assisted selection, would use genetic markers associated with desirable production characteristics to enhance genetic improvement. If such markers prove to be accurate predictors, they will allow selection of desirable animals long before performance records are available. Transfer of desirable genes, within or between species, may also expedite the generation of superior animals. The goal of animal breeding can be expected to remain similar to that of the past—namely the improvement of animal species to better meet human needs—but the precise nature of the improvements desired and the methodologies used to achieve them could be vastly different.

—*James L. Robinson*

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