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Biotechnology and Various Environmental Concerns: An Introduction

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1.1 Introduction

Károly Ereky, a Hungarian engineer, first used the term "biotechnology" in 1919 to describe the science and techniques that allow products to be made from raw materials with the help of living organisms. Biotechnology is broadly defined as using living organisms or the products of living organisms for human benefit (or to benefit human surroundings) to make a product or solve a problem [1]. This technology has been used for thousands of years and involves working with cells and bacteria to produce various products useful for mankind. The best examples include the fermentation used to make breads, cheese, yogurt, and alcoholic beverages such as beer and wine. However, modern biotechnology is a multidisciplinary subject that involves the sharing of knowledge between different areas of science such as cell and molecular biology, genetics, microbiology, anatomy and physiology, computer science, biochemistry, and recombinant DNA technology (rDNA technology).

The foundation of modern biotechnology was laid down with the advancements in science and technology during the eighteenth and nineteenth centuries. Between 1850 and 1860, Louis Pasteur developed the process of pasteurization. By 1860, he also concluded that organisms did not occur as a result of spontaneous generation; all cells arise from preexisting cells. At the beginning of 1857, Gregor Mendel developed genetics and the Principles of Heredity, where he cross-pollinated pea plants to examine traits such as petal color, seed color, and seed texture. In 1869, J. F. Miescher isolated "nuclein" from the nuclei of white blood cells, which contain nucleic acids. In 1882, German cytologist Walter Flemming described that during mitosis, thread-like bodies (chromosomes) were equally distributed to daughter cells during cell division. In 1896, Eduard Buchner showed that biochemical transformations can take place without the use of cells by converting sugar to ethyl

Biotechnology in Environmental Remediation, First Edition.
Edited by Jaspal Singh, Rajesh Bajpai, and Ravi Kumar Gangwar.

alcohol using yeast extracts. In 1928, Alexander Fleming discovered *Penicillium* inhibited the growth of a bacterium called *Staphylococcus aureus*, responsible for skin disease in humans.

Many novel experiments were conducted during the 20th century, like identification of DNA as the genetic material by the classical Alfred Hershey and Martha Chase in 1952, followed by the double helical structure of DNA proposed by James Watson and Francis Crick in 1953. In 1978, Boyer was able to isolate a gene for insulin (a hormone to regulate blood sugar levels) from human genome using biotechnology. In 1997, Ian Wilmut was successful in cloning a sheep named "Dolly." In 2003, the Human Genome Project completed the sequencing of the human genome.

The multidisciplinary nature of modern biotechnology and the areas of its application are given in Figure 1.1 and Table 1.1.

Biotechnology has revolutionized diagnostics and therapeutics; however, lethal virus diseases like avian flu, Chikungunya, Ebola, influenza A, SARS, West Nile, Zika virus, and the most recent coronavirus have posed the greatest risks to humans. Scientists and researchers are continuously adapting to various biotechniques to tackle these threats. Moreover, biotechnology has provided novel opportunities for the sustainable production of various products and services. Additionally, environmental concerns encourage the use of biotechnology for biomonitoring as well as ecologically friendly chemical synthesis, waste minimization, and pollution management (decontamination of water, air, and soil).

In Chapter 2, the importance, contribution to agriculture and environment, and future prospects of plant biotechnology have been discussed. To ensure that

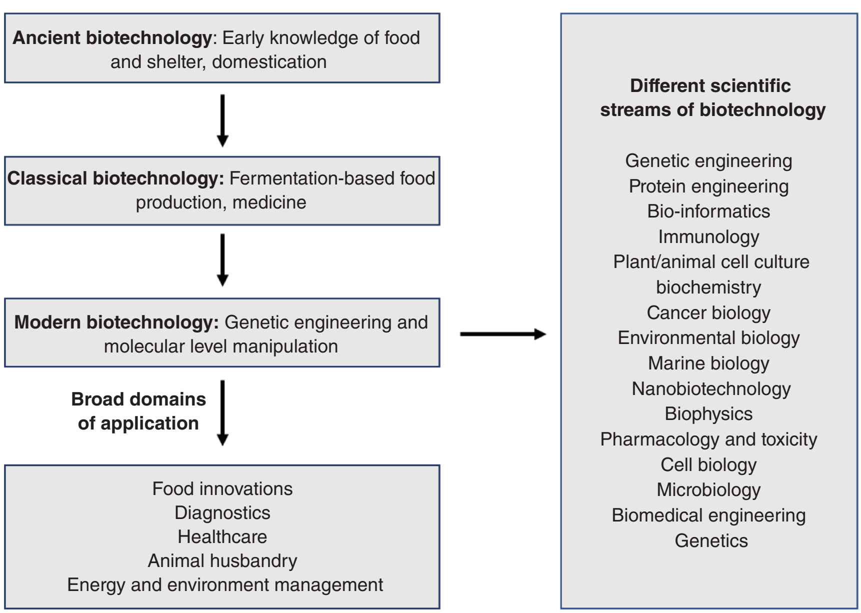

Figure 1.1 Multidisciplinary nature of modern biotechnology and the areas of its application. Source: NCERT [2].

Table 1.1 Some common areas of biotechnology.

Biotechnology area	Products/applications
Industrial (White) biotechnology	Enzymes, fermentation products, biochemicals, reagents, etc.
Agricultural (Green) biotechnology	Golden rice, drought-tolerant crops, transgenic crops, salt-tolerant crops, etc.
Marine (Blue) biotechnology	Aquatic organisms, aquaculture, increasing sea food, etc.
Medical (Red) biotechnology	Vaccines, antibodies, therapeutic proteins, antibiotics, stem cells, gene therapy, etc.
Environmental biotechnology	Pollution detection, composting, bioremediation, phytoremediation, bioextractions, transgenic modifications, etc.

Source: Adapted from Gupta et al. [3].

environmental resources are preserved for future generations, deliberate efforts must be undertaken to identify alternatives and ways to use them sustainably. This chapter seeks to provide an introduction to plant biotechnology, covering its fundamentals, where research has taken it thus far, the need for it, its place in agriculture, and how it might help solve agricultural and environmental problems. The chapter places a strong emphasis on debunking myths about genetically modified organisms (GMOs), including how they are made in the plant kingdom, the advantages they provide, and the problems they have. The reader will have a better grasp of how scientific ideas developed for the enhancement of crops for farmers and those who depend on agriculture are used in the actual world.

Furthermore, metals and hydrocarbons are considered hazardous materials because they have the potential to cause cancer and mutagenic consequences in humans. Forest fires, transportation, and various industrial operations are the main causes of this environmental pollution. These metals and hydrocarbons are major constituents of petroleum. The effects of petroleum and hydrocarbons on microbes, soils, plants, and human health are discussed in Chapter 3. As microorganisms extract xenobiotic organic and inorganic substances from the environment and totally mineralize them into carbon dioxide, water, and inorganic compounds during biodegradation, this chapter also discusses the functions of microorganisms in the breakdown of hydrocarbons and several processes used in the process, including enzymes, biosurfactants, and immobilization. Additionally, the function of aerobic and anaerobic pathways as well as several parameters for hydrocarbon breakdown are described.

Recent decades have seen an increase in environmental contamination as a result of several increasing anthropogenic activities. A popular and efficient technique for eliminating hazardous material from a contaminated environment is "bioremediation." Bioremediation is extensively involved in the degradation, eradication, immobilization, or detoxification of a wide range of chemical wastes and physically dangerous compounds from the environment through the all-inclusive activity of microorganisms. Heavy metals, nuclear waste, pesticides, greenhouse gases, and hydrocarbons are among the pollutants that threaten the environment and public health due to their toxicity. The organisms involved in bioremediation, as well as the variables influencing microbial bioremediation, are all covered in Chapter 4. Additionally, this chapter provides details on the types and methods of bioremediation. It also covers the advantages, disadvantages, and drawbacks of bioremediation.

Chapter 5 makes an attempt to evaluate the function of soil biodiversity in environmental sustainability as it relates to sustaining terrestrial life and biodiversity, climate change, hydrological dynamics, and environmental remediation. Numerous soil processes that provide a variety of ecosystem goods and services are driven by soil biodiversity. Soil organisms are closely linked to a number of ecosystem services, including nutrient cycling, climate regulation, water infiltration, and purification, through their activity and interactions. The effort to link soil biota to specific functions that support soil-based ecosystem services is difficult due to the complicated interaction between soil biodiversity and ecosystem function. Its ability to provide different ecosystem services is also significantly influenced by other environmental conditions and soil management practices. Therefore, in order to maximize biodiversity's potential for environmental sustainability, it must be comprehended, evaluated, and managed sustainably.

The main constituents of soil biodiversity are microorganisms. Plant growth-promoting rhizobacteria (PGPR), which are naturally occurring soil microorganisms, are helpful to plant growth and have the ability to encourage plant growth by colonizing the plant roots [4]. PGPR's roles such as the production of indoleacetic acid (IAA), ammonia (NH_3), hydrogen cyanide (HCN), catalase, and others are discussed in Chapter 6. PGPR promotes seed germination, seedling growth, and yield. Many microorganisms such as *Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Alcaligenes, Arthrobacter, Burkholderia, Bacillus*, and *Serratia* promote plant growth. Seed inoculation, alone or in combination with bacterial cultures/products, to increase nutrient availability through various processes such as phosphate solubilization, nitrogen fixation, and soil applications that are gaining popularity are presented in Chapter 6.

Chapter 7 focuses on the biological capture of CO_2 using microalgae to minimize carbon footprint and other methodologies to compare with biological CO_2 fixation. The drastic increase in CO_2 concentration in the atmosphere resulted in climate change. To tackle this problem, conventional carbon capture and storage (CCS) technology is not economically useful for its long-term application in mitigating climate change. These conventional approaches to reduce CO_2 concentration have several technological and economic limitations. Therefore, it is essential to identify suitable alternatives to the current technologies and to improve existing techniques in order to reduce CO_2. Hence, various biological carbon dioxide (CO_2)-capturing technologies, such as using microalgae, absorption, adsorption, membrane separation, and other biological methods, were discussed in Chapter 7. Out of which, microalgae have been very promising in the recycling of CO_2 into biomass, and they can assimilate 10–50 times more CO_2 than vascular plants without providing food to humans/animals [5]. It will also lessen the amount of additional carbon dioxide released into the atmosphere and reduce the burden on industries that produce high-value goods.

In Chapters 8 and 9, the importance of lichens is discussed. Lichens are remarkable alliances of nature, a composite organism arising from fungus and algae. They may live and flourish in a variety of climatic and biological settings all around the world. Lichens are extremely useful economically and commercially as ingredients for perfumes, colors, ayurvedic medicines, food, fodder, flavoring agents, spices, and sauces, among other products. Additionally, lichens have recently become significant to the pharmaceutical sector as a result of the discovery of physiologically active compounds in lichens. Due to their slow rate of growth in their natural habitat, lichens are vulnerable to extinction if their commercial use is not restricted. In order to conserve these organisms in nature, *in vitro* production of lichens or their constituent parts may offer a viable approach. Furthermore, *in vitro* culture of lichens and its components for studying the biosynthetic pathways and their manipulation to enhance the production of valuable secondary metabolites are presented in Chapter 8.

Another lichen, *Cladonia*, of the family Cladoniaceae is more dominant in the Indian Himalayan regions. Cladonioid community has fumarprotocetraric acid, which contains species that have special traits and prefers to grow on soil, dead decaying wood, and soil over rocks. The Cladoniaceae family is an intriguing source of bioactive substances that offer many prospects for developing new antioxidant, antibacterial, and anticancer medicines. Because of the potential uses suggested by the research, Cladoniaceae lichens may be useful in the food, pharmaceutical, and agricultural sectors. Chapter 9 discusses the structure and composition of the lichen family Cladoniaceae in six Himalayan states of India, together with a comparative assessment of functional traits varied in different habitats and metabolites. The qualitative assessment of secondary metabolites will also serve as a baseline for the development of green medicines in the near future through biotechnological applications.

Water is essential for all life forms. The quality of the water is getting worse every day due to the growing world population, excessive water usage, and overexploitation of the water resources. Industrial activities and agricultural activities, particularly the excessive and irrational use of fertilizers and other chemicals, damage freshwater bodies. This problem of wastewater treatment can be solved by biotechnology, which can also aid in the evaluation of water quality. The applications of biotechnology for wastewater remediation are an efficient and environmentally friendly strategy because they require fewer chemicals and fewer laborers to regulate. Chapter 10 focuses on the use of biotechnological methods for the remediation of wastewater. GMOs like *Pseudomonas* spp. (Super Bug) and biologically advanced systems for the remediation of polluted aquatic bodies for industrial wastewater treatment were also discussed. Various bioremediation processes that involve the use of micro- and macroorganisms along with activated sludge process, trickling filters, membrane bioreactors, and constructed wetlands are presented in Chapter 10.

With a growing population, energy demand is increasing unprecedentedly. To meet this demand, crude oil is currently acting as a primary source of energy. However, the consumption of a vast quantity of these nonrenewable fossil fuels resulted in the release of various environmental contaminants. Thus, incorporation of clean and green technologies with the aim of achieving sustainable development is now of great concern. Biotechnological and microbiological techniques have shown great potential for biofuel production using crops and other organic waste, the generation of wind and solar energy, and the development of alternative energy through renewable, nonpolluting resources. The contribution of biotechnology to energy production has significant potential to increase not only in biofuel production but also in producing energy from petro-crops, biochar, petroleum production, petroleum upgrading, and biogas production. Chapter 11 focuses on the developments in biotechnological applications to create more advanced biofuels and offer a better and more sustainable fuel economy globally.

Another biotechnological approach to remediate environmental pollutants for a cleaner environment is "nanotechnology." A number of organic and inorganic pollutants that are harmful to both the environment and human health have been introduced into the environment as a result of growing industry, urbanization, and population growth worldwide. The potential of nanotechnology in environmental cleanup has been demonstrated in Chapter 12. Pollutants are removed from the environment using a variety of nanomaterials, including carbon-based, inorganic, and polymeric-based compounds. Nanomaterials can be used to successfully remove synthetic colors, heavy metals, pesticides, organophosphorus chemicals, chlorinated organic compounds, and volatile organic compounds. These environmental contaminants could potentially alter the composition of the environment and pose health risks to humans [6]. Nanomaterials can be used in water, soil, or air because of their adaptability and wide range of forms. In this chapter, the use of nanoparticles for environmental cleanup is briefly covered. It presents the most recent developments in the use of metal, carbon, polymer, and silica nanoparticles in the treatment of wastewater, soil, and air.

In the modern era, microorganisms are frequently used in bioremediation to remove organic and inorganic pollutants from our environment. Microbes are widely applied in various fields like pollution mitigation, biofuel and enzyme production, food industries, agriculture, and medical science. Microbes' interactions with their surroundings, in particular, are influenced by the surface of their cells. Biomolecules found on the surface of microbial cells control their fluidity or hydrophobicity, which determines whether they are attracted to hydrophilic or hydrophobic substances. Higher hydrophobicity in microbial cells has been linked to a variety of microbial behaviors, including cell aggregation, biodegradation of organic pollutants, biofilm development, and resistance to hydrophobic substances. To effectively utilize these potent natural agents for their various applications, it is important to understand the biomolecules that influence cell surface hydrophobicity (CSH). Chapter 13 discusses the different cell surface biomolecules (fatty acids and proteins) that are being reported as responsible for the alteration of CSH, along with the environmental factors that influence microbial cell hydrophobicity.

For a healthy environment, chemical sustainability is essential, as these are a necessary part of everyday life. Humans are widely exposed to toxic chemicals present in domestic, environmental, and occupational setups. This exposure may be of the acute, brief-duration type, or it may be persistent. People working in various industries that deal with asbestos, battery recycling facilities, tanneries, lead smelting plants, paint factories, etc. are more likely to be exposed to hazardous chemicals at the workplace. Chemical sustainability, commonly referred to as sustainable chemistry, is the effective introduction of novel chemicals, processes, and products while sustaining environmental and public health protection. The Organisation for Economic Co-operation and Development (OECD) is greatly concerned about these global issues, and it helps countries by implementing regulations that support economic growth and the smart and efficient use of resources. The use of biomass as an energy source should also be encouraged as one of the ways to reduce dependence on fossil fuels. Enzyme technology advancements through protein engineering and bioremediation technology have also been very successful in reducing urban waste management. Chapter 14 will cover the scope of chemical sustainability, current research in chemical sustainability, regulatory requirements, significant regulatory contributions in various countries, particularly India, potential benefits, and hidden cons.

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