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A Review of Biotechnology Advancements as Key Drivers of Scientific Innovations

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Abstract

The rising human challenges have necessitated the quest to find lasting solutions to improve living standards. Challenges in food security in terms of quality and quantity, medical and health issues, energy deficiency and limitations in areas of transportation, domestic and industrial needs, as well as environmental issues are some major areas of application of biotechnology to sustain human existence. This review examines major scientific innovations driven by biotechnology. Biotechnology applied to improve microorganisms have provided such innovations as fermented foods, biofuels, antibiotics, enhanced degradation, and drug syntheses. Plant biotechnology has also brought about innovations to achieve food security through biofortification, phytoremediation, pathogen-resistant and tolerant crops, and tissue culture. Animal and aquatic biotechnology have also provided innovations in breeding animals with desired traits ultimately for food and other industrial products to sustain humans. Environmental biotechnology has contributed to bioremediation, biofuel generation, and monitoring of environmental media. Similarly, medical biotechnology has improved human well-being by producing vaccines and drugs to treat or prevent diseases and correct genetic disorders. This paper gives an overview of current knowledge of biotechnology in driving scientific innovations, which ultimately solves societal challenges and improves human livelihood.

Keywords: Biotechnology, scientific innovation, genetic engineering, biofuels, medical biotechnology

INTRODUCTION

The use of biological systems and processes to create products that are aimed at improving human lives is called biotechnology [1]. It involves engineering of organisms for improving human livelihoods. It also involves the use of living systems or modifying natural processes to create products and systems for human development. It is a multifaceted and multidisciplinary field that integrates biology, technology, and engineering.

Since the days of old, biotechnology has existed in crude ways when humans first employed fermentation to produce and modify foods and drinks. Today, biotechnology has grossly expanded our knowledge and abilities through the application of scientific and technological advancements [2–4]. One of the subfields of biotechnology is genetic engineering, which involves modifying and enhancing the genetic composition of an organism. Biotechnology is transforming many sectors of human lives, such as agriculture and food systems, where genetically altered crops with better resistance to pests, diseases and environmental variables are being developed. This method boosts food production and yield [5].

Biotechnology is applied in different fields of study to either create or modify products to meet human needs. These applications include the following:

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- *Agriculture:* Biotechnology is applied in different agriculture systems, including organic agriculture, genetically engineered crops, and agrochemical-based agriculture. The overall aim is to grossly increase food production, sometimes up to 100% increase. Biotechnology also benefits farmers by offering crops resistant to pests and diseases, as well as genetically modified (GM) crops, which increase food production, and ultimately meet food needs of the growing human population [6].
- *Aquaculture:* Biotechnology is applied in fish production to improve production, both in quality and quantity. Fishes are being stimulated with gonadotropin-releasing hormone to enhance breeding, which then enhances growth, desirable genetic characteristics and productivity. Biotechnology is also applied to reduce disease incidences in fish production, ultimately saving investments of fish breeders, and ensuring fish supply for consumers.
- *Transgenic Animals:* Biotechnology is applied in producing transgenic animals, which are animals whose genes are modified through genetic engineering. Animals, such as cows, fish, pigs, rabbits, rats, etc., are being produced to study and discover treatments for different animal diseases. This technology is also employed to test vaccine safety and drug toxicity to animals, and to produce certain biological products. The genes are also modified as a way of developing favorable genes in the animals.
- *Medicine:* Genetic engineering allows for recombination of DNA, that allows for wider production of safe and effective drugs to treat human ailments. For instance, the genetically modified insulin, called Humulin, is used in treatment of diabetes in humans. Gene therapy is also developed as a proactive way to remove genetic disorders at the embryo stage in humans [7–9].
- *Antibiotics and Vaccines:* Biotechnology is employed to produce antibiotics, vaccines, and hormones using plants and microorganisms. In such plants and microorganisms, genes possessing desired traits are being induced to produce encoded proteins. Such products are cheaper, have longer shelf-life, and are easy to administer in the human body. They are also widely used in treating human diseases, such as cholera, hepatitis, measles, etc. [10–14].

MICROBIAL BIOTECHNOLOGY

Microorganisms play a crucial role in the field of biotechnology, as they find applications in many industrial processes. In the fermentation process, microorganisms convert raw materials into valuable products like beer, wine, and biofuels. Recombinant DNA technology is a biotechnology application that recombines genes in microbes to produce therapeutic proteins, which has improved the field of medicine [15–17]. Microbial bioprocessing also plays a major role in biofuel and special chemical production, highlighting the role of microorganisms in modern biotechnology [18–21]. Microorganisms have been incorporated in other industrial processes, including food production and waste management systems. In essence, microbial biotechnology has many potentials, such as the genetically engineered bacteria that produce insulin, yeast strains that synthesize bioethanol, and many more applications, are being discovered [22].

Recent biotechnology advancements have revealed previously unidentified microbial species with unique metabolic functions. Research on the human microbiome has provided significant insights into the influence of microorganisms on human health, while the application of Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR) technology for genome edits has broken new frontiers in microbial research. These trends offer a glimpse into the future of microbiology, and its potential applications across various disciplines [23]. In food production systems, fermentation processes have been enhanced and applied in much more varieties of food items using microbes, which are sustainable ways of developing food varieties.

Different microbial communities serve various ecological purposes including nutrient cycling, disease prevalence, and ecosystem sustainability. Many of these fundamental processes are now applied in biotechnology to speed up processes that would take longer under natural circumstances. For instance, restoring ecosystem stability and functions, food preservation, food enhancements. In waste management systems, microbes are being explored to degrade pollutants and remediate polluted ecosystems, playing vital roles in recycling elements and practicing sustainability in various industries. Exploring the importance of microorganisms in biotechnology reveals a wide range of potential applications [24].

MICROBIAL GENETIC ENGINEERING

Microbial genetic engineering is a field of biotechnology, involving techniques aimed at manipulating microbial DNA. One technique that has advanced this field is the Polymerase Chain Reaction (PCR), a key technique that enables targeted gene amplification with great precision [25]. The PCR technique provides a basis for subsequent genetic modifications by enabling selective replication of specific DNA segments. Another advancement in microbial genetic engineering emerged with the discovery of CRISPR-Cas system, once considered a prokaryotic immune system. The CRISPR-Cas system has improved genetic engineering processes, by enabling precise and efficient genome editing in microorganisms. Another notable aspect of microbial genetic engineering involves synthetic gene circuits, which enable creation of complex genetic networks within microorganisms. The principles of synthetic biology play a crucial role in modifying microbial strains with specific functionalities [26]. In other biotechnology applications, CRISPR can be incorporated into synthetic gene circuits for better precision [27] and better control over gene expression in the microorganisms, resulting in development of microbial strains with enhanced and customizable features.

Role of Microbes in Bioprocessing

Microorganisms can synthesize many valuable compounds and thus play vital roles in bio-production systems. For example, *Escherichia coli* and *Saccharomyces cerevisiae* are being engineered to produce recombinant proteins [28]. Microbial strains are also being engineered for biofuel production, showing the potential of biotechnology in contributing to sustainable energy solutions [29]. The success of this microbial production depends on careful optimization of bioprocess parameters, as factors, such as temperature, pH, and nutrient concentrations, determine microbial growth rate and product generation.

Microbial Bioremediation

Biotechnology has found applications in microbial bioremediation. The oil-degrading bacteria, *Pseudomonas putida*, is one of the microbes used in microbial bioremediation. This microbe is used at oil-spill sites to break down the hydrocarbons, thus mitigating the environmental impact of oil spills [30]. Also, the white-rot fungus, *Phanerochaete chrysosporium*, possesses high degradation ability for complex and persistent pollutants, such as polychlorinated biphenyls (PCBs), thus removing recalcitrant compounds and remediating ecosystems [31]. Genetic engineering introduces precision to microbial bioremediation efforts, making it possible to design microbes with enhanced abilities for remediation. Modifying microbial genes, e.g., insertion of genes encoding for specific enzymes (e.g., cytochrome P450 for pesticide degradation) into microbial genomes, enables targeted degradation of pollutants [32]. However, biotechnological applications in environmental remediation require careful consideration of ethical concerns and potential ecological impacts, necessitating stringent evaluation and regulation.

Microbial Fermentation

Microbial fermentation occupies a central role in biotechnology applications, through which a wide range of products have been developed and enhanced. One organism with remarkable fermentation ability is yeast, Saccharomyces cerevisiae. S. cerevisiae has been widely utilized in both small and large-scale ethanol production, which is used by many industries for various purposes. Ethanol produced through microbial fermentation has a potential to meet the demands of sustainable biofuels, especially when produced from waste materials [33–35]. Microbial fermentation is also significant for its role in production of antibiotics. Furthermore, microbial fermentation is involved in the production of several biochemical compounds, which are inputs in many industrial processes. Several other bioactive compounds, such as amino acids, vitamins, and other bioactive molecules, are the products of microbial fermentation. Synthesis of vitamin B12 through microbial fermentation by the bacterium, Propionibacterium freudenreichii, also show the significance of microbial fermentation [36, 37] in addressing nutritional needs and supporting human health. With advancements in biotechnology, microbial fermentation continues to evolve with respect to increasing efficiency and scalability. Recent emphasis on sustainability incorporated into microbial fermentation processes, emphasize that resources are maximized and environmental impacts reduced. The use of fermentation products in industrial processes also aligns with sustainability.

SYNTHETIC MICROORGANISMS

Biotechnology has been applied in developing synthetic microorganisms, which are microorganisms designed with specific features created by manipulating genetic information. This process utilizes advanced DNA assembly methods and innovative computer-aided design tools. Many improvements and contributions to these methods have improved the accuracy of the functioning of these microorganisms [38, 39]. The genetic components are carefully organized using DNA assembly methods, resulting in synthetic microorganisms with customized features. These microbes are then applied to solve certain problems across various fields [40]. Many strategies are used to design microorganisms with precision and accuracy. However, the overall aim is beyond creating more microorganisms, but more about careful coordination of interplay of genes to accomplish certain tasks.

Many synthetic microorganisms serve as microbial cell factories, whose metabolites are being used as essential compounds in synthesis of biofuels, pharmaceuticals and other important chemicals. For example, genetic information in *Escherichia coli* is being manipulated for production of artemisinin, a key compound in antimalarial drugs [41]. This shows that this technique can be adapted to solve many societal challenges. Its precise and customized approach to providing solutions reveals it as a promising sustainable solution.

Microbial Metabolic Engineering

Microbial metabolic engineering is another application in biotechnology that involves altering normal microbial pathways, for improved production of specific biochemicals. During this process, certain genes are over-expressed, while others are deleted to achieve desired metabolic flux. *E. coli* is being engineered for increased biofuel production [42], and *Saccharomyces cerevisiae* for better bioethanol production [43]. This application is vital for enhancing biological processes that improve yield and productivity. Some specific techniques that offer more precise metabolic engineering are adaptive evolution [44] and dynamic flux balance [45]. This technique allows for a good understanding of cellular processes, and expertise developed allows for improved designs. Also, genes from other higher organisms are being engineered into microorganisms, such as *E. coli*. The capability of eukaryotic genes to perform within prokaryotic cells indicates the interconnectedness of life at the molecular level [46].

Microbial Biotechnology in Medicine

In medicine, microbial biotechnology has found applications by using engineered microorganisms to produce drugs and treat various diseases. This opened a new dimension to the active role of microorganisms in therapy. Probiotics and genetically modified bacteria are major examples, which are widely used in therapeutic solutions. Genetically modified bacteria are used as carriers of therapeutic proteins [47]. Gastrointestinal disorders are also being managed using live bio-therapeutic products from engineered microorganisms [48]. This nexus between medicine and microbial engineering has potential for targeted treatments, minimal side effects and high effectiveness.

In drug production, microbes ae explored to synthesize therapeutic proteins and drugs. *Escherichia coli* and yeast are key players in recombinant protein production [49]. *Aspergillus niger* is also a major player in the industrial production of citric acid. These microbial systems are fundamental to the pharmaceutical industry and healthcare sector, ensuring a continuous, cost-efficient, sustainable and eco-friendly production of essential drugs.

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The human body is a kind of ecosystem; due to the various microbial communities it houses. Some of these communities are mimicked in biotechnological innovations to solve medical issues. Some microbiome-based therapies include the fecal microbiota transplantation (FMT) show the interventions of these microbial communities in medicine. In FMT, gut microbiota is collected from healthy donors and transferred to patients having such ailments as *Clostridium difficile* infection. This method has explored the benefits inherent in the mutual relationship of the microbial communities and the human gut. In addition, there are also options of personalized treatments designed to suit an individual's unique microbial composition. There are still many unexplored aspects as this field unfolds, with a goal to provide therapies for yet, many more ailments.

Microbial biosensors are another set of tools used in microbial biotechnology, which provide fast, cost-effective detection of medical conditions. Engineered microorganisms are designed to detect specific biomarkers or pathogens, thus aiding in medical diagnostics. They can detect disease-related molecules in clinical samples and assist in early and accurate detection of disease conditions. The luminescent bacteria-based biosensors, initially developed by Belkin in 2003 for monitoring water quality, are now used in medical diagnostics.

PLANT BIOTECHNOLOGY

Plant biotechnology is a branch of biotechnology that aims to enhance crop yields to satisfy the rising food needs of the human population [4]. This field is also known as agricultural biotechnology. It includes both traditional and contemporary breeding methods that modify living organisms or their parts to develop products for agricultural purposes. Plants are being genetically engineered to lower production costs and effectively manage agricultural processes, to increase crop yield. Some crops are engineered to better tolerate specific herbicides used to selectively control weeds, to effectively resist certain plant diseases and pests for reliable pest management, and to discourage the use of chemical pesticides. Improvements in crop production provide countries with the ability to meet their food demands and lower the production costs. Another aspect of plant biotechnology is developing genetically modified plants for phytoremediation purposes, where plants detoxify or absorb soil contaminants. These plants are then harvested, and the pollutants removed in controlled environments for safe disposal or storage, ultimately enhancing soil quality.

Plant biotechnology offers numerous benefits for farmers, food processing industries, and consumers. Improved pest and disease management, as well as weed control, are achieved in a safe and efficient manner with biotechnology. For instance, using genetically engineered pest-resistant cotton plant species significantly reduces pesticide use, and benefits both the environment and public health. Other crops being developed to tolerate herbicides, allow for the use of herbicides that degrade easily, and are non-toxic to humans and wildlife. These herbicide-tolerant crops aid faster weed control, leaving the crops of interest unaffected. They are also suitable in non-tillage or low-tillage farming systems, thereby protecting topsoil from erosion. Biotechnology has also aided breeding of halophytes (plants that thrive in saline soils) and drought-tolerant plants, which are aimed at adapting to and mitigating effects of climate change.

Agricultural biotechnology incorporates techniques, such as genetic engineering, vaccine and tissue culture, and molecular diagnostics. In genetic engineering, desired traits are transferred by inserting DNA from plants, animals, or microorganisms into the plants. In tissue culture, disease-free plant parts are propagated under controlled conditions to grow healthy crops. Molecular diagnostics are useful to identify specific genes and gene products, for accurate diagnosis of plant diseases.

Biotechnology also develops new plant strains with better yield and lower production costs. These crops can survive a wide range of environmental conditions, potentially conserving natural resources. Biotechnology also provides harvests of high-quality crops with longer shelf life either in storage or during transport, thus providing consumers with low-cost food options.

While plant biotechnology focuses mainly on improving crop yield and crop productivity, concerns on micronutrient deficiency have been raised. However, this field of biotechnology now aims to achieve food security both in terms of adequate quantity and quality of food through bio-fortification. Biofortification produces nutrient-rich foods in adequate amounts, helping to combat hunger and malnutrition in developing countries of the world. Biofortification is a sustainable, long-term strategy where many staple foods already contain micronutrients at harvest time, and there is no need for further enrichment during processing of the crops or before consumption.

ANIMAL BIOTECHNOLOGY

Many techniques in plant biotechnology are similar in animal biotechnology. In recombinant DNA technology, genes in animals are being modified for specific traits to be expressed or over-expressed. For instance, the human insulin gene is being transferred to the bacterium, *E. coli*, for the commercial production of human insulin [17]. Insulin is widely needed by human diabetic patients, and this application helps to make it readily available. Using genetic engineering techniques, genes from a variety of living organisms are being introduced into animals for enhancing their health or productivity.

Biotechnology applications in animals include selective breeding to improve desired traits, such as color, size, shape, and agility. This has been widely used in breeding different species of dogs [18]. Genetic engineering is also useful in producing transgenic animals, where either novel or modified genes are inserted into an animal's genome. This technique has been successfully used for cows, fish, rabbits, rats, and sheep. A major purpose of transgenic animals is to develop disease-resistant animals. Transgenic animals are also useful for testing for the safety of human drugs and vaccines, promoting production of biological end products, studying gene regulation on health status and development of animals, and studying the effects of the specific genes on the animal genome [4].

Biotechnology has also been applied in animal cloning. In 1996, the first mammal was cloned and named "Dolly". It was formed from a fully differentiated somatic cell of a sheep. This was achieved by scientists in Scotland who cloned the sheep's siblings Polly and molly. The creation of "Dolly" challenged the fundamental principle of developmental biology. Udder cells from a six-year-old sheep, and unfertilized egg of another adult sheep were extracted. The egg was de-nucleated, and a non-dividing nucleus of the udder cell was inserted into the de-nucleated egg. In culture medium, embryo formation began as the egg started to cleave (divide). A third sheep (surrogate mother) was employed, and this young embryo was implanted in its uterus. The surrogate mother (a fertile female) birthed a normal healthy lamb, called "Dolly". With the successful clone of "Dolly", the possibility of human cloning has been strengthened. Many geneticists all over the world are trying to develop human clones. However, it has been banned by the governments of many countries because of certain social and ethical issues [19].

AQUATIC BIOTECHNOLOGY

Aquatic biotechnology involves processes in aquatic environments (both freshwater and marine). These processes include fish production, and production of biofuels and pharmaceuticals, through conversion of aquatic biomass. Biotechnology has become integral to fish production, particularly in aquaculture, where its applications are diverse and impactful, such as in genetic improvement. Through selective breeding and genetic engineering, researchers and aqua-culturists enhance desirable fish characteristics, such as faster growth rates, heightened disease-resistant species, improved tolerance to environmental variables, and more efficient utilization of feed. By carefully selecting breeding pairs or introducing specific genes into fish populations, farmers can cultivate stocks that are better suited to their production goals and environmental conditions [20].

Another vital role of biotechnology in fish production lies in disease management. Aquatic environments can be susceptible to various pathogens that can devastate fish populations. Biotechnology advancements have led to developing vaccines and diagnostic tools tailored to specific pathogens affecting fish. Vaccination programs can help prevent outbreaks, while diagnostic tools enable early detection and targeted treatment of diseases, reducing their impact on fish health and production [21].

Furthermore, biotechnology contributes to fish nutrition by enabling the production of specialized feeds. Fish require specific nutrients for optimal growth and health, and biotechnology allows for the development of feeds tailored to different species and life stages. This includes the use of genetically modified organisms (GMOs) to produce feed ingredients with enhanced nutritional profiles, such as soybeans or algae, engineered to contain higher levels of essential fatty acids or proteins. Techniques, such as hormone manipulation and *in vitro* fertilization, are utilized to regulate spawning and breeding in aquaculture settings. These methods help optimize reproduction, increasing the efficiency and reliability of hatchery operations [22]. Overall, biotechnology enhances various aspects of fish production, from genetic improvement and disease management to nutritional advancements and reproductive optimization, ultimately contributing to the sustainability and productivity of aquaculture systems.

ENVIRONMENT AND BIOTECHNOLOGY

Biotechnology applications aid better understanding of the natural environment, and harness biological processes for sustainable production of certain human needs, such as food, nutrients, renewable energy, etc. [23]. Biotechnology is also applied to degrade environmental pollutants and oil cleanup. Environmental biotechnology has several applications, including biomarkers and biosensors.

Biomarkers react to chemicals in the environment and help to assess the effects of pollution. They may also affect biological responses at the molecular and cellular levels, including physiological and behavioral changes from exposure to certain chemical pollutants. On the other hand, biosensors are analytical devices that use biological materials. They are designed for sensitive organic elements, such as tissues, antibodies, cell receptors, enzymes, organelles, nucleic acids, other natural products, and even complete microorganisms [24]. Biosensors are particularly useful for detecting concentrations of toxins in ecosystems.

BIOREMEDIATION

Biotechnology is applied in bioremediation, a procedure that employs living organisms, e.g., microorganisms and plants, to remove contaminants and pollutants from different environmental media. Bioremediation is widely used in cleaning up contaminated groundwater, and oil spills resulting from oil exploration or transportation. During bioremediation, organisms are stimulated to grow by using constituents of the contaminants and pollutants (including oils, solvents, pesticides, plastics, etc.) as nutrient or energy sources. During this process, these compounds are transformed into water and harmless gases (e.g., carbon dioxide) as end products [25].

Bioremediation relies on the right combination of nutrients, food sources and environmental conditions, to achieve efficient cleanup. Where any of these variables are lacking, the addition of certain amendments, such as improved airflow, molasses, and vegetable oil, etc., improves the process. These amendments optimize the conditions for the organisms to flourish and hasten the bioremediation process. Bioremediation can occur *in situ* when it takes place at the exact site of contamination, and *ex situ* when it takes place at a location away from its contamination site. *Ex situ* bioremediation can be expensive when it requires removal of soil to a different location for cleanup. It is, however, necessary when the soils are compact and nutrient distribution is uneven, or if the weather condition is unfavorable to the organisms being used for bioremediation [25].

Advantages of Bioremediation

There are several advantages of choosing bioremediation over other methods of environmental cleanup. One of these is that bioremediation relies completely on natural processes and thus minimizes potential harm to ecosystems. Another advantage is that bioremediation can also occur underground, and amendments and microorganisms can be pumped there to remove groundwater and soil contaminants. Also, bioremediation does not cause disruption of biological communities like other cleanup methods. Bioremediation also creates fewer harmful by-products (the product of most contaminants or pollutants are mainly water and non-toxic gases, e.g., CO_2). Bioremediation is also cheaper compared to other cleanup methods, as it requires relatively low technologies and labor input [25].

BIOFUEL

Biofuel is a type of fuel derived from living organisms or their remains. It is a renewable source of energy obtained from the biomass of microorganisms, plants or animals. As with other conventional fuel sources, biofuels can exist in solid, liquid or gaseous states. However, most biofuels are produced in the liquid and gaseous states for ease of transportation and usage. Examples of solid biofuels include wood chips, biochar, etc. Examples of the other groups of biofuels are ethanol (commonly sourced from maize and sugarcane), biodiesel (commonly sourced from animal fats and plant-derived oils), green diesel (obtained from plants and algae), and biogas (CH_4 obtained through anaerobic composting of digested plant and animal wastes) [38].

The energy demand all over the world continues to increase and puts pressure seeking alternative and sustainable solutions to the current fossil fuel use. Biofuels have been functioning as alternatives to fossil fuels, and release energy to power vehicles, machinery and for heating in homes. Biofuels are being encouraged because they are produced from renewable organic materials that are infinite, their emissions are very low, and their production processes have less impact on the environment [39].

Limitations of Biofuel

The global concerns about greenhouse emissions and energy security have made biofuels being considered viable alternatives to use of fossil fuels. However, there are also limitations of biofuels. There is a cost-benefit issue, where more ethanol is needed to produce the same amount of energy that gasoline would produce. It was thus wasteful to use ethanol, because producing ethanol for biofuel results in a net energy loss, and increases food prices. Certain conservation groups have argued that bio-crops would serve a better purpose as a food source, rather than as a fuel source. Similarly, large amount of arable land is required for bio-crop production and there are concerns about this due to limited land for food production, deforestation, fertilizer run-off, soil erosion and soil salinity [40].

Algae Cultivation as Alternatives

In addressing the large expanse of arable land needed for biofuel production, biofuel companies are exploring water-based solutions for better algae productivity, where algae are cultivated on lands unsuitable for food or other purposes, and water used is also unusable in food production. As such, non-arable lands and non-freshwater are used. Algae yield a larger quantity of biofuel per acre compared to other sources. Also, the biofuels produced from algae cultivation are much like the conventional fuels currently used in transportation and machinery, which is a significant advantage. Thus, it has better potential to replace conventional fossil fuels [41].

Biomonitoring

Another biotechnology application is use of biomonitoring, the process of measuring the chemicals in human body tissues and fluids, including blood, breast milk, saliva, hair and urine, to give information on the individual's exposure to environmental contaminants. These measurements provide information on chemicals taken into the human body from different exposure pathways and estimate the cumulative chemical concentration or body burden of individual. The exposure differences among several groups within and among populations, as well as changes in exposure of these population groups over time can be identified using biomonitoring [42].

MEDICAL BIOTECHNOLOGY

Medical biotechnology is a field of medicine that utilizes living cells, cell organelles, or cellular components to produce pharmaceuticals and diagnostic products. The aim is to prevent and cure diseases in living organisms. This field has made significant advancements, contributing to health improvements through initiatives, such as the development of the Ebola vaccine and the mapping of human DNA. It has also been used to produce vaccines and drugs in treating plant and animal diseases. Recent applications have been in areas of drug treatments, genetic testing and artificial tissue regeneration [43]. Major advancements in medical biotechnology include CRISPR, tissue nano-transfection, recombinant DNA technology, genetic testing, stem cell research, and personalized medicine.

CRISPR

The CRISPR technology, also called CRISPR-Cas9, uses Cas9 protein, a type of molecular scissors, to cut DNA. These specific DNA segments are utilized as tools for genome editing. This technology, which allows DNAs and gene functions to be modified, is termed genetic engineering. The applications of CRISPR include correction of genetic defects, treatment of diseases, and prevention of diseases [44].

Tissue Nano-transfection (TNT)

In the process of TNT, genetic codes are injected into skin cells to transform them into cells capable of treating diseases. TNT shows promise in repairing damaged cells and tissues in both animals and humans within a short timeframe, as evidenced by numerous laboratory trials. This genetic therapy holds significant potential for restoring health, particularly in victims of automobile accidents and injured soldiers [45].

Recombinant DNA Technology

Recombinant DNA technology involves combining DNA segments from two or more related species and inserting this mixed DNA into a different host species to obtain a new genetic combination. This method is useful for producing biopharmaceuticals and diagnostic tools [46].

Genetic Testing

Genetic and ancestry testing kits enable individuals to gain insights into their genetics and heritage. Recently, advancements in genetic testing have emerged for the prediction and prevention of medical conditions. One example is utilizing saliva kits to assess saliva and identify potential gene mutations linked to breast cancer. Similar predictions have been made for other conditions, such as Parkinson's disease, facilitating proactive measures for prevention [47].

Stem Cell Research

Stem cells are undifferentiated cells, that is, cells that can develop into specific types of cells in living organisms, e.g., embryonic cells. Stem cell research is an application of medical biotechnology, to repair and restore dead or damaged cells in humans. These stem cells are being grown in the laboratories or *in vitro*. Stem cells can be implanted or ingested to restore the health of many patients who may be suffering from diseases or disorders. The ability of stem cells to divide and become other body cells has encouraged biotechnologists to explore their usage [48].

Personalized Medicine

This branch of medical biotechnology is relatively new. Personalized medicine focuses on creating more targeted and specific treatments tailored to individual patients, ensuring effective medical interventions. It encompasses several areas, including pharmacogenomics, aimed at enhancing medications through genomic testing [49].

Pharmaceutical Biotechnology

Pharmaceutical biotechnology involves new technologies for formulating and synthesizing biological materials to produce drugs for the treatment and prevention of the current and emerging diseases. Pharmaceutical biotechnology contributes to the discovery and development of drugs, by examining disease patterns, and therapeutic and treatment interventions, including vaccines [50].

CONCLUSIONS

The application of biotechnology has led to remarkable achievements, challenges, and collaborative efforts that drive scientific innovations. The influence of biotechnology has reshaped various sectors including healthcare, agriculture, environmental conservation, and more. Healthcare is being personalized and more efficient, food systems are being more reliable and sustainable, and environmental stewardship is heightened. These applications demonstrate human creativity, scientific inquiry, and the quest to address pressing human challenges. Improving on current applications and addressing ethical concerns are necessary for the future of biotechnology in our societies. This may involve embracing new techniques and promoting interdisciplinary collaboration. Biotechnology, as a driving force for scientific innovations, is being shaped by scientists, researchers, and innovators globally. Scientific innovations have improved the quality of life with time, and biotechnology holds the potential to do much more in a changing world.

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