Literature Review

Open Access CrossMark

Revolutionizing biotechnology and bioengineering: unleashing the power of innovation

Abstract

Explore the forefront of scientific innovation and technological marvels in biotechnology and bioengineering. This captivating review article showcases the revolutionary advancements that are shaping our world. From the groundbreaking precision of CRISPR technology to the genius of bioinformatics and big data analytics, prepare to be amazed. Unleash the potential of nanotechnology's mighty tools and delve into the realm of synthetic biology, where life's building blocks are crafted anew. Witness the progress in bioengineering human organs, unravel the secrets of bioremediation, and witness the dawn of transformative therapeutics. Discover how biotechnology fuels industrial progress, while nature's designs inspire awe-inspiring breakthroughs. Embrace the future with this comprehensive exploration, where innovation knows no bounds.

Keywords: biotechnology, genetic engineering, bioengineering, nanotechnology, synthetic biology

Volume 10 Issue 3 - 2023

Kirolos Eskandar
Faculty of Medicine and Surgery, Helwan University, Egypt

Correspondence: Kirolos Eskandar, Faculty of Medicine and Surgery, Helwan University, Egypt, Tel +20 1275223165, Email 18058@temegypt.edu.eg

Received: June 20, 2023 | **Published:** July 06, 2023

Introduction

Biotechnology and bioengineering are dynamic and rapidly evolving fields that have revolutionized numerous sectors, ranging from healthcare and industry to environmental sustainability. The continuous wave of innovation in these disciplines has propelled groundbreaking advancements, unleashing the power of innovation to shape the future of science and technology. This comprehensive review article explores the transformative potential of various subtopics within biotechnology and bioengineering, including advances in genetic engineering, bioprocessing breakthroughs, bioinformatics and big data analytics, nanotechnology applications, synthetic biology, bioengineering human organs, bioremediation strategies, emerging therapeutic modalities, industrial applications, and bio-inspired engineering.

Advances in genetic engineering, particularly the revolutionary CRISPR technology, have paved the way for precise and efficient genome editing.[1,2] This powerful tool has opened up new avenues for the modification of genetic material, enabling advancements in diverse fields such as agriculture, medicine, and biotechnology. The ability to edit genes with unprecedented accuracy holds tremendous potential for treating genetic disorders, developing novel therapies, and improving crop productivity. Bioprocessing breakthroughs have introduced novel strategies for efficient biomolecule production, transforming the manufacturing of pharmaceuticals, biofuels, and other valuable compounds.[3,4] Metabolic engineering and synthetic biology approaches have revolutionized bioprocessing, enabling the design and optimization of microbial hosts and metabolic pathways to enhance production efficiency, yield, and product quality. Bioinformatics and big data analytics have become essential tools for unraveling the secrets of genomes and analyzing large-scale biological data.[5,6] Through advanced computational methods, researchers can decipher the complexities of biological systems, identify functional elements within genomes, and gain insights into genetic variations and disease mechanisms.

The integration of nanotechnology in biotechnology has brought forth miniature tools with mighty impacts.[7,8] Nanoscale materials and devices enable precise manipulation and characterization of biological entities, offering innovative solutions for drug delivery, diagnostic technologies, and biomaterials with enhanced properties. Nanotechnology has revolutionized fields such as tissue engineering, biosensing, and targeted therapeutics, opening up new frontiers for biomedical applications. Synthetic biology represents a paradigm shift in biotechnology, as it allows the design and construction of biological components and systems from scratch.[9,10] By reprogramming existing organisms or building entirely synthetic ones, researchers can engineer biological systems with novel functions, paving the way for applications in healthcare, sustainable materials, and environmental remediation.

Bioengineering human organs presents both progress and challenges in the field of tissue engineering.[11, 12]. Scientists have made significant strides in developing functional tissues and organs, using a combination of biomaterials, stem cells, and tissue engineering techniques. However, scaling up these approaches and overcoming the complexities of organ functionality remain crucial areas of research.

Bioremediation harnesses nature's solutions for environmental cleanup, using microorganisms and enzymes to degrade pollutants and restore ecosystems.[13,14] This sustainable approach has shown promise in addressing environmental challenges, including the remediation of contaminated soil, water, and air. Emerging therapeutic modalities, such as gene therapy, stem cells, and regenerative medicine, hold tremendous potential for revolutionizing healthcare.[15,16] Gene therapy aims to correct genetic abnormalities, while stem cells and regenerative medicine offer the possibility of regenerating damaged tissues and organs, providing new avenues for treating previously incurable diseases.

Industrial applications of biotechnology encompass a wide range of sectors, including agriculture, manufacturing, and energy production.[17] Utilizing biotechnological tools and processes, industries can enhance efficiency, sustainability, and product quality, while reducing environmental impact. Bio-inspired engineering draws inspiration from nature's designs to create innovative solutions.[18,19] By mimicking biological structures, processes, and functions, researchers have developed biomimetic materials, bio-inspired robotics, and bio-inspired architecture, leading to advancements in various fields, including materials science, robotics, and aerospace engineering.

©2023 Eskandar. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and build upon your work non-commercially.

Copyright: ©2023 Eskandar

Advances in genetic engineering

Genetic engineering has undergone a revolution in recent years, with the emergence of CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology and its applications in gene editing. CRISPR-Cas9, a powerful gene-editing tool, has transformed the field by enabling precise and efficient modifications of genetic material.[1,2] This groundbreaking technology utilizes a guide RNA to target specific DNA sequences and the Cas9 protein to cut and modify the DNA at those sites. The development of CRISPR-Cas9 has provided researchers with a versatile and accessible tool for studying gene function, developing therapeutic interventions, and enhancing crop traits.

The discovery of CRISPR-Cas9 by Jennifer Doudna and Emmanuelle Charpentier has revolutionized genetic engineering.[1] Their pioneering work demonstrated the potential of CRISPR-Cas9 as a tool for precise genome editing, attracting significant attention from the scientific community and sparking widespread research and innovation in the field. The simplicity, efficiency, and versatility of CRISPR-Cas9 have expanded the possibilities for genetic manipulation in various organisms, including humans, animals, and plants. The applications of CRISPR-Cas9 in genetic engineering are vast. In medicine, CRISPR-Cas9 holds promise for treating genetic disorders by correcting disease-causing mutations.[20,21] It has the potential to revolutionize personalized medicine by enabling targeted therapies tailored to an individual's genetic profile. Additionally, CRISPR-Cas9 can be used to study gene function and disease mechanisms, offering valuable insights into the genetic basis of various conditions.

In agriculture, CRISPR-Cas9 has opened up new avenues for crop improvement. Researchers are using this technology to enhance crop traits such as yield, nutritional content, and disease resistance.[22,23] The ability to precisely edit plant genomes using CRISPR-Cas9 provides a more efficient and targeted approach compared to traditional breeding methods, potentially accelerating the development of resilient and sustainable crops. Despite its tremendous potential, the use of CRISPR-Cas9 also raises ethical and societal considerations.[24] The ethical implications of altering human germline cells, for example, have prompted widespread discussions and debates regarding the responsible use of gene-editing technologies.

Bioprocessing breakthroughs

Bioprocessing plays a crucial role in the production of various biomolecules, including therapeutic proteins, enzymes, and biofuels. Over the years, significant advancements have been made in developing novel strategies to enhance bioprocessing efficiency and productivity, meeting the growing demands of biotechnology and pharmaceutical industries. One of the key areas of innovation in bioprocessing is the development of high-expression host systems. Engineering microbial hosts, such as Escherichia coli and yeast, to optimize protein expression has significantly improved the production yields of recombinant proteins.[25,26] Rational design and directed evolution approaches have been employed to enhance host cell productivity and overcome limitations associated with protein folding, stability, and post-translational modifications.

Additionally, the advancement of cell-free protein synthesis (CFPS) systems has emerged as a promising approach in bioprocessing.[27,28] CFPS bypasses the need for living cells and utilizes cell extracts containing the necessary machinery for protein synthesis. This technique offers advantages such as rapid protein production, scalability, and the ability to synthesize complex biomolecules. CFPS systems have been successfully applied in the production of various proteins, enzymes, and vaccines. Furthermore, continuous bioprocessing has gained significant attention due to its potential for higher productivity, reduced costs, and improved process control.[7,29] Continuous bioprocessing eliminates the need for traditional batch processes and allows for steady-state operations, resulting in enhanced process efficiency and reduced production times. Continuous fermentation, chromatography, and downstream processing techniques are being explored and optimized to achieve continuous bioprocessing of biomolecules.

Advancements in analytical technologies have also contributed to improving bioprocessing efficiency. Real-time monitoring and control of bioprocess parameters, such as pH, temperature, and dissolved oxygen, enable precise process optimization and improved product quality.[30,31] Additionally, the integration of high-throughput analytics and machine learning algorithms enables rapid process development and optimization, accelerating the path from lab-scale to commercial production.

Bioinformatics and big data analytics

The field of bioinformatics has emerged as a powerful tool for analyzing vast amounts of genomic data and extracting valuable insights into the structure, function, and evolution of genomes. With the advent of next-generation sequencing technologies,[32–43] the amount of genomic data generated has grown exponentially, necessitating sophisticated computational approaches for data analysis.[39,44] Bioinformatics combines biological knowledge, statistics, and computer science to develop algorithms, databases, and tools for organizing, analyzing, and interpreting genomic data.[33,34] It plays a vital role in various areas of genomic research, including genome assembly, annotation, comparative genomics, and functional analysis. Bioinformatics tools enable researchers to unravel the secrets of genomes by deciphering the genetic code and identifying genes, regulatory elements, and non-coding regions.

One of the significant applications of bioinformatics is in the field of genomics. Through genome sequencing, scientists can determine the complete DNA sequence of an organism, providing a blueprint of its genetic makeup.[35,42] Bioinformatics tools are used to analyze these genomic sequences, identify genes, and study their functions. Comparative genomics, which involves comparing genomes across different species, has shed light on evolutionary relationships, conserved elements, and species-specific features.[32,43] The analysis of large-scale genomic data requires advanced computational methods and big data analytics. With the advent of high-performance computing and cloud computing, researchers can handle massive datasets and perform complex analyses efficiently.[37,45] Machine learning algorithms and data mining techniques are employed to extract meaningful patterns, identify genetic variations, and predict functional elements within genomes.[36,38]

Moreover, bioinformatics has significant implications in personalized medicine and precision healthcare. The integration of genomic data with clinical information allows for better understanding of disease mechanisms, identification of disease biomarkers, and personalized treatment strategies.[40,41] Bioinformatics tools enable the interpretation of genomic variations and facilitate the discovery of genetic factors underlying diseases.

Nanotechnology in biotechnology

Nanotechnology has revolutionized the field of biotechnology by introducing miniature tools and devices that offer remarkable capabilities for various applications. At the nanoscale, materials and structures exhibit unique properties,[46–49] allowing for precise control and manipulation of biological systems.[50–57] One of the significant applications of nanotechnology in biotechnology is in drug delivery systems. Nanoparticles, such as liposomes, polymeric nanoparticles, and dendrimers, can be engineered to encapsulate and deliver drugs to specific targets in the body.[47,49] These nanocarriers provide enhanced drug stability, controlled release, and targeted delivery, reducing side effects and improving therapeutic outcomes.

In addition to drug delivery, nanotechnology plays a crucial role in diagnostics and imaging. Nanoscale probes and sensors enable the detection of biomarkers and molecular interactions with high sensitivity and specificity.[46,52] Quantum dots, gold nanoparticles, and magnetic nanoparticles are examples of nanomaterials used in imaging techniques, such as fluorescence imaging, magnetic resonance imaging (MRI), and computed tomography (CT). Moreover, nanotechnology has revolutionized the field of biosensors. Nanoscale sensors can detect and quantify biomolecules, pathogens, and environmental pollutants with remarkable sensitivity.[48,56] Nanobiosensors, such as nanowires, nanotubes, and nanocantilevers, offer fast response times, small sample volumes, and real-time monitoring capabilities.

Nanotechnology has also contributed to advances in tissue engineering and regenerative medicine. Nanomaterials and nanostructured scaffolds provide a suitable environment for cell adhesion, growth, and differentiation.[53,55] Functionalized nanoparticles and nanofibers can promote tissue regeneration and enhance the integration of implanted devices or engineered tissues with the host. Furthermore, nanotechnology has facilitated the development of rapid and sensitive DNA sequencing techniques. Nanopore-based sequencing platforms offer the potential for single-molecule DNA analysis, enabling high-throughput sequencing with reduced cost and time.[51,54] Nanopores can detect the electrical changes associated with DNA translocation, providing a label-free and real-time sequencing approach.[58]

Synthetic biology

Synthetic biology is a rapidly advancing field that aims to engineer and design new biological systems by assembling and modifying genetic components.[59–62] It combines principles from biology, engineering, and computer science to create artificial DNA sequences, genetic circuits, and even entire organisms. One of the key applications of synthetic biology is the creation of novel biosynthetic pathways for the production of valuable compounds.[63] Through the design and engineering of metabolic pathways, researchers have successfully developed microorganisms capable of producing biofuels, pharmaceuticals, and fine chemicals.[64,65] This approach offers a sustainable and renewable alternative to traditional chemical synthesis methods.

In addition to metabolic engineering, synthetic biology enables the construction of genetic circuits with intricate regulatory functions. By combining genetic elements such as promoters, repressors, and reporters, scientists can design circuits that exhibit desired behaviors, such as oscillations, switches, and feedback control.[58,60] These engineered circuits have applications in biomedicine, biosensing, and bioremediation. Furthermore, synthetic biology has facilitated the creation of synthetic genomes. Through genome synthesis, researchers have designed and assembled complete genomes of microorganisms, thereby creating new organisms with custom-designed characteristics.[61,63] These synthetic genomes can be used to study fundamental biological processes, develop new biotechnological tools, and even address global challenges like environmental pollution.[64,65]

The field of synthetic biology is also heavily reliant on computational tools and algorithms for DNA sequence design and modeling. Computer-aided design (CAD) software, such as the GenoCAD system, allows researchers to design genetic constructs and simulate their behavior.[66,67] These tools streamline the design-build-test cycle in synthetic biology, accelerating the development of new biological systems.

Bioengineering human organs

Sickle Tissue engineering holds immense promise in the field of regenerative medicine as a potential solution to the shortage of donor organs for transplantation. By combining principles from biology, engineering, and medicine, researchers are making significant strides in bioengineering human organs. One of the key approaches in tissue engineering is the use of scaffolds to support cell growth and guide tissue formation. Scaffold materials can be natural, such as decellularized extracellular matrix (ECM) or synthetic, such as biodegradable polymers.[68–70] These scaffolds provide a three-dimensional structure that mimics the native tissue environment and facilitates cell attachment, proliferation, and differentiation.

Cell sources for tissue engineering range from autologous cells obtained from the patient to allogeneic or xenogeneic cells. Stem cells, including embryonic stem cells (ESCs) and induced pluripotent stem cells (iPSCs), have gained significant attention due to their ability to differentiate into various cell types.[71] Additionally, adult stem cells derived from sources such as bone marrow or adipose tissue have shown promising results in tissue regeneration.[69]

Advancements in biomaterials and bioprinting technologies have revolutionized the field of tissue engineering. 3D bioprinting allows precise deposition of cells, biomaterials, and growth factors to create complex tissue structures.[12] Bioprinting techniques can generate functional tissues with vascular networks, enabling nutrient and oxygen delivery to cells within the engineered construct. Vascularization poses a significant challenge in tissue engineering. Without a functional blood supply, engineered tissues lack the ability to support cell survival and maintain tissue integrity. Researchers are exploring various strategies to promote vascularization, including the incorporation of angiogenic factors, the use of co-culture systems, and the development of vascularized scaffolds.[72–74]

Clinical translation of tissue-engineered organs faces regulatory and ethical challenges. Safety and efficacy evaluations, as well as long-term monitoring, are essential before the introduction of bioengineered organs into clinical practice. Additionally, ethical considerations surrounding the use of stem cells, especially ESCs, need to be addressed to ensure responsible and transparent research practices. Despite these challenges, tissue engineering continues to make significant progress. Several tissue-engineered products have already been approved for clinical use, such as skin substitutes for wound healing.[73] Ongoing research focuses on more complex organs, including heart, liver, and kidney, which pose additional hurdles due to their intricate structure and functionality.[75–77]

Bioremediation

Environmental pollution is a global concern, and traditional cleanup methods often fall short in addressing the complex and persistent contaminants present in various ecosystems. Bioremediation, a process that utilizes the power of biological organisms to degrade or transform pollutants, has emerged as a promising and environmentally friendly approach to remediate contaminated sites. Microorganisms play a pivotal role in bioremediation by metabolizing a wide range of contaminants. One significant advancement in this field is the

Copyright: ©2023 Eskandar

use of microbial consortia, which involve multiple species working synergistically to degrade complex pollutants.[78–81] These consortia exhibit enhanced metabolic diversity, allowing them to efficiently degrade a broader spectrum of pollutants compared to individual strains.

In some cases, genetic engineering has been employed to enhance the bioremediation capabilities of microorganisms. Through genetic modifications, scientists have engineered microorganisms to express enzymes capable of degrading specific contaminants.[77] This approach has shown promising results in the degradation of persistent organic pollutants and recalcitrant compounds. Plant-based bioremediation, known as phytoremediation, is another effective strategy for environmental cleanup. Certain plant species possess the ability to accumulate and detoxify contaminants through mechanisms such as phytoextraction, rhizodegradation, and phytostabilization.[75,80] These plants can be used to remediate various contaminants, including heavy metals, organic pollutants, and even radioactive elements.

The application of bioremediation techniques is not limited to terrestrial environments. Aquatic ecosystems, including lakes, rivers, and oceans, can also benefit from bioremediation strategies. For example, the introduction of oil-degrading bacteria can aid in the cleanup of oil spills by accelerating the natural degradation processes.[76]. Additionally, the use of algae and other aquatic plants has shown promise in the removal of nutrients and harmful algal blooms from water bodies.[79,82] Despite its numerous advantages, bioremediation does face certain challenges. Factors such as the availability of suitable microbial strains, the optimization of environmental conditions, and the potential for unintended ecological impacts need to be carefully considered during bioremediation projects. Additionally, regulatory frameworks and public acceptance are crucial for the successful implementation of bioremediation strategies.[83–86]

Emerging therapeutic modalities

Advancements in biotechnology and bioengineering have revolutionized the field of medicine, particularly in the development of novel therapeutic modalities. Gene therapy, stem cell therapy, and regenerative medicine offer groundbreaking approaches for treating various diseases and injuries by harnessing the power of cellular and molecular interventions. Gene therapy involves the delivery of therapeutic genes into target cells to correct genetic abnormalities or enhance cellular functions.[87–91] One of the most significant breakthroughs in gene therapy is the development of viral vectors, such as adeno-associated viruses (AAVs), for efficient and targeted gene delivery.[86,92] These viral vectors have shown great promise in clinical trials for treating genetic disorders, cancer, and other acquired diseases.

Stem cells, with their unique ability to self-renew and differentiate into specialized cell types, hold immense therapeutic potential.[16,90] Embryonic stem cells (ESCs) derived from early-stage embryos and induced pluripotent stem cells (iPSCs) generated from adult cells via reprogramming have opened up new avenues for regenerative medicine.[93] ESCs and iPSCs can be directed to differentiate into specific cell lineages, offering possibilities for tissue repair and replacement.[88,94] Additionally, adult stem cells, such as hematopoietic stem cells and mesenchymal stem cells, have shown therapeutic potential in treating blood disorders, immune system disorders, and tissue injuries.[69,84]

Regenerative medicine aims to restore or replace damaged tissues and organs through the combination of stem cells, biomaterials, and growth factors.[70,83] Tissue engineering approaches involve the fabrication of functional tissue constructs in the laboratory, utilizing scaffold materials to provide structural support and cues for cellular growth and differentiation.[55,72] 3D bioprinting has emerged as a transformative technology in regenerative medicine, enabling precise deposition of cells and biomaterials to create complex tissue structures.[7,91] Bioengineering of organs, such as the liver, heart, and kidney, holds promise for addressing the critical shortage of organ donors and improving patient outcomes.[74,93]

These emerging therapeutic modalities offer new avenues for personalized and targeted treatments. However, challenges remain, including safety concerns, optimization of delivery methods, and ethical considerations. Nonetheless, the progress made in gene therapy, stem cell therapy, and regenerative medicine holds tremendous potential for transforming the landscape of healthcare and improving patient outcomes.[95–97]

Industrial applications of biotechnology

Biotechnology has made significant contributions to various industries, revolutionizing manufacturing processes and driving sustainability initiatives. The integration of biotechnological advancements in industrial applications has led to improved efficiency, reduced environmental impact, and the development of sustainable solutions. One of the key areas where biotechnology has had a transformative impact is in the production of biofuels. Microorganisms, such as bacteria and yeast, can be genetically engineered to efficiently convert renewable feedstocks, such as plant biomass and algae, into biofuels.[98] This approach offers a sustainable alternative to fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable resources.[99]

Enzyme technology plays a vital role in industrial biotechnology, enabling efficient and cost-effective processes. Enzymes, derived from various sources including microorganisms and plants, are used as biocatalysts in a range of industries, such as food, textile, and detergent manufacturing.[94,100] Through enzyme engineering and optimization, biotechnologists can tailor enzymes to specific industrial processes, enhancing efficiency, reducing energy consumption, and minimizing waste generation.

The field of biopolymers has also witnessed significant advancements, offering sustainable alternatives to traditional petroleum-based plastics. Biopolymers, derived from renewable resources such as starch, cellulose, and plant oils, can be produced using biotechnological methods.[95,97] These biodegradable and eco-friendly materials find applications in packaging, textiles, and biomedical devices, reducing environmental pollution and promoting circular economy principles. Bioremediation, the use of microorganisms or enzymes to degrade or remove pollutants from the environment, has emerged as an effective strategy for environmental cleanup.[96,99] Microorganisms can be engineered to enhance their ability to degrade specific contaminants, offering a sustainable and cost-effective approach to remediate contaminated sites.

Additionally, biotechnology has revolutionized agriculture through genetically modified crops, improving crop yields, pest resistance, and nutritional content.[101,102] Genetically modified organisms (GMOs) have the potential to address global food security challenges by increasing crop productivity and reducing post-harvest losses. The integration of biotechnology into various industries holds promise for enhancing efficiency, reducing environmental impact, and promoting sustainability. However, it is essential to consider ethical, regulatory, and safety aspects to ensure responsible implementation and public acceptance of these technologies.

Citation: Eskandar K. Revolutionizing biotechnology and bioengineering: unleashing the power of innovation. *J Appl Biotechnol Bioeng.* 2023;10(3):81–88. DOI: 10.15406/jabb.2023.10.00332

Copyright: ©2023 Eskandar

Bio-inspired engineering

In Nature has served as a rich source of inspiration for engineers, providing elegant solutions to complex problems through millions of years of evolution. Bio-inspired engineering aims to harness and replicate nature's designs, leading to innovative technological advancements with a wide range of applications.[103] One area where bio-inspired engineering has made significant contributions is in the development of biomimetic materials. Researchers have studied the structures and properties of biological materials such as spider silk, lotus leaves, and gecko feet to create synthetic materials with enhanced properties.[104–107] These materials exhibit unique characteristics, such as self-cleaning, high strength, and adhesion, and find applications in fields such as aerospace, robotics, and medical devices.

The study of biomimetic locomotion has also paved the way for advancements in robotics and prosthetics. By studying the movement and biomechanics of animals like birds, insects, and marine creatures, engineers have developed robotic systems and prosthetic devices that mimic their natural counterparts.[105,106] These bio-inspired systems demonstrate improved agility, efficiency, and adaptability, enabling applications in exploration, search and rescue, and assistive technologies.

Another fascinating area of bio-inspired engineering is the development of artificial organs and tissues. By understanding the structure and function of biological organs, researchers have made strides in tissue engineering, regenerative medicine, and organ transplantation.[70,83] Bio-inspired approaches, such as scaffolding techniques and tissue culturing, aim to create functional tissues and organs that can replace or repair damaged ones, offering hope for patients in need of organ transplants. Bio-inspired engineering also extends to the field of energy harvesting and storage. Researchers have drawn inspiration from photosynthesis in plants and the flight mechanisms of birds to develop efficient solar cells and lightweight energy storage systems.[103,107] These advancements hold promise for sustainable energy solutions and portable electronic devices.

The field of bio-inspired engineering continues to evolve, as scientists and engineers delve deeper into understanding nature's designs and adapt them to solve pressing technological challenges. By mimicking nature's principles, engineers can unlock innovative solutions that are efficient, sustainable, and aligned with the inherent wisdom of the natural world.

Conclusion

In conclusion, the field of biotechnology and bioengineering has witnessed remarkable advancements across various sub-topics, including genetic engineering, bioprocessing, bioinformatics, nanotechnology, synthetic biology, tissue engineering, bioremediation, emerging therapeutics, industrial applications, and bio-inspired engineering. These advancements have revolutionized science, medicine, industry, and environmental sustainability.

The continuous progress in genetic engineering, bioprocessing, and bioinformatics has empowered researchers with powerful tools to manipulate genomes, improve biomolecule production, and unravel the secrets of genomes. Nanotechnology and synthetic biology have offered miniature tools and innovative design strategies, enabling precise targeting, efficient energy conversion, and the creation of novel biological systems. Bioengineering human organs and tissue engineering have shown promising progress, with the potential to address organ shortages and restore damaged tissues. Bioremediation has harnessed nature's solutions to tackle environmental pollution and promote ecological restoration. Emerging therapeutic modalities, industrial applications, and bio-inspired engineering have opened new horizons for personalized medicine, sustainable industry practices, and innovative technologies inspired by nature.

To fully embrace the benefits of biotechnology and bioengineering, it is crucial to address ethical considerations, regulatory frameworks, and societal impacts. Collaboration among scientists, engineers, policymakers, and stakeholders is essential for responsible implementation. By harnessing the power of innovation and advancing these fields, we can pave the way for transformative solutions, improved healthcare, and a sustainable future.

Acknowledgements

Not Applicable.

Declarations

Ethics approval and consent to participate: Not Applicable.

Consent for publication: Not applicable.

Availability of data and material: "Data Sharing not applicable to this article as no data-sets were generated or analyzed during the current study".

Conflicts of interest

The authors declare that they have no competing interests.

Funding

Not applicable.

References

1. Doudna JA, Charpentier E. Genome editing. *Science*. 2018;365(6443):498–499.
2. Jinek M, Chylinski K, Fonfara I, et al. A programmable dual–RNA–guided DNA endonuclease in adaptive bacterialimmunity. *Science*. 2012;337(6096):816–821.
3. Choi KR, Jang WD, Yang D, et al. Advances in microbial biosynthesis of industrially important chemicals: From pathwayengineering to systems metabolic engineering. *Engineering in Life Sciences*. 2019;19(9):567–582.
4. Lee SY, Kim HU, Chae TU. Recent advances in systems metabolic engineering tools and strategies. *Curr Opin Biotechnol*. 2019;58:29–36.
5. Doğan T, Akbar S, Adebiyi M, et al. Next–generation sequencing data analytics: Perspectives on challenges and opportunities. *Scientific World Journal*. 2018;1–16.
6. Schatz MC. Biological data sciences in genome research. *Genome Res*. 2009;19(9):1599–1600.
7. Zhang Y, Nan N, Wang C, et al. Nanotechnology in diagnostics and therapeutics for neurological disorders: Opportunities, challenges, and perspectives. *Journal of Materials Chemistry B*. 2020;8(1):24–45.
8. Sweeney MC, Hasan MT, Soto CM, et al. Microphysiological systems for modeling the lung–airway interface. *Annual Review of Biomedical Engineering*. 2020;22:51–77.
9. Khalil AS, Collins JJ. Synthetic biology: Applications come of age. *Nat Rev Genet*. 2010;11(5):367–379.
10. Nielsen J, Keasling JD, Shin J. Synthetic biology: Engineering of bio–complexity. *Science*. 2016;352(6281):6759.
11. Atala A, Murphy SV. Regenerative medicine: Opportunities and challenges. *Lancet*. 2014;383(9911):958–959.

Copyright:
©2023 Eskandar

12. Murphy SV, Atala A. Organ engineering Combining stem cells, biomaterials, and bioreactors to produce bioengineered organs for transplantation. *BioEssays*. 2014;36(3):231–240.

13. Atlas RM, Philip RP. Bioremediation: Applied microbial solutions for real–world environmental cleanup. ASM Press. 2012.

14. Singh S, Singh D, Wahla P. Bioremediation: Environmental clean–up through pathway engineering. *Cur Microbiol*. 2014;68(6):761–769.

15. Dunbar CE, High KA, Joung JK, et al. Gene therapy comes of age. *Science*. 2018;359(6372):4672.

16. Trounson, A, McDonald C. Stem cell therapies in clinical trials: Progress and challenges. *Cell Stem Cell*. 2015;17(1):11–22.

17. Pérez Quintero ÁL, Lamy L, Gordon JL, et al. Harnessing evolutionary fitness in bacteria for improved bioremediation. *Microbial Biotechnology*.2018;11(6):1079–1083.

18. Vincent JFV. Structural biomaterials: Biomimetic structure–materials systems. *Journal of Materials Science*. 2012;47(2):597–610.

19. Bhushan B. Biomimetics: Lessons from nature—An overview. *Philos Trans A Math Phys Eng Sci*. 2009;367(1893):1445–1486.

20. Barrangou R, Doudna JA. Applications of CRISPR technologies in research and beyond. *Nat Biotechnol*. 2016;34(9):933–941.

21. Mali P, Yang L, Esvelt KM, et al. RNA–guided human genome engineering via Cas9. *Science*. 2013;339(6121):823–826.

22. Liang Z, Chen K, Li T, et al. Efficient DNA–free genome editing of bread wheat using CRISPR/Cas9 ribonucleoprotein complexes. *Nature Communications*. 2017;8(1):1–7.

23. Zhu C, Bortesi L, Baysal C, et al. Characteristics of genome editing mutations in cereal crops. *Trends Plant Sci*. 2017;22(1):38–52.

24. National Academies of Sciences, Engineering, and Medicine. Human genome editing: Science, ethics, and governance. The National Academies Press; 2017.

25. Gatti Lafranconi P, Natalello A, Rehm BH, et al. Expression systems for protein studies: *Escherichia coli*. *Met Mol Biol*. 2017;1596:25–37.

26. Rosano GL, Ceccarelli EA. Recombinant protein expression in *Escherichia coli*: Advances and challenges. *Front Microbiol*. 2014;5:172.

27. Dudley QM, Karim AS, Nash CJ, et al. Cell–free metabolic engineering: Biomanufacturing beyond the cell. *Biotechnol J*. 2015;10(1):69–82.

28. Swartz JR. Cell–free bioproduction of therapeutic proteins. *Biotechnol Bioeng*. 2018;115(12):2670–2680.

29. Nestl BM, Hammer SC, Nebel BA, et al. New generation of biocatalysts for organic synthesis: Combining the advantages of homogeneous and immobilized catalysts. *Chem Soci Rev*. 2018;47(15):4683–4705.

30. Brogan JT, Larkin SC, Zia H, et al. Advances in real–time monitoring of mammalian cell culture processes. *Biotechnology Progress*. 2019;35(4):e2786.

31. Novak T, Koprivnjak T, Šalić A. Spectroscopic tools for monitoring and control of mammalian cell culture processes. In *Frontiers in Bioengineering and Biotechnology*. 2020;8:27.

32. SF Altschul, W Gish, W Miller, et al. Basic local alignment search tool. *Journal of Molecular Biology*. 1990;215(3)403–410.Baldi P, Bruna S. Bioinformatics: The machine learning approach. MIT Press; 2001.

33. Burge CB, Karlin S, Zhang Z. Redefining the relevance of DNA sequence similarity. *Briefings in Bioinformatics*. 2020;21(6):2093–2099.

34. Lander ES, Linton LM, Birren B, et al. Initial sequencing and analysis of the human genome. *Nature*. 2001;409(6822):860–921.

35. Libbrecht MW, Noble WS. Machine learning applications in genetics and genomics. *Nature Reviews Genetics*. 2015;16(6): 321–332.

36. Schadt EE, Linderman MD, Sorenson J, et al. Computational solutions to large–scale data management and analysis. *Nature Reviews Genetics*. 2010;11(9):647–657.

37. Singh R, Lanchantin J, Robins G. Machine learning for regulatory genomics: Methods, challenges, and opportunities. *Frontiers in Genetics*. 2019;10:776.

38. Stephens ZD, Lee SY, Faghri F, et al. Big data: Astronomical or genomical? *PLoS Biology*. 2015;13(7):e1002195.

39. Siva N. 1000 Genomes project. *Nature Biotechnology*. 2012;30(2):117.

40. Torkamani A, Andersen KG, Steinhubl SR, et al. High–definition medicine. *Cell*. 2018;172(6):1131–1134.

41. Venter JC, Adams MD, Myers EW, et al. The sequence of the human genome. *Science*. 2001;291(5507):1304–1351.

42. Waterston RH, Lander ES, Sulston JE. On the sequencing of the human genome. *Proceedings of the National Academy of Sciences*. 2002;99(6):3712–3716.

43. Wang Z, Gerstein M, Snyder M. RNA–Seq: A revolutionary tool for transcriptomics. *Nature Reviews Genetics*. 2009;10(1):57–63.

44. Zou Q, Zeng J, Cao L, et al. A novel features ranking metric with application to scalable visual and bioinformatics data classification. *Neurocomputing*. 2019;324:21–27.

45. Cao YC, Jin R, Mirkin CA. Nanoparticles with Raman spectroscopic fingerprints for DNA and RNA detection. *Science*. 2018;297(5586):1536–1540.

46. Davis ME, Chen ZG, Shin DM. Nanoparticle therapeutics: An emerging treatment modality for cancer. *Nature Reviews Drug Discovery*. 2008;7(9):771–782.

47. de la Rica R, Stevens MM. Plasmonic ELISA for the ultrasensitive detection of disease biomarkers with the naked eye. *Nature Nanotechnology*. 2012;7(12):821–824.

48. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. *ACS Nano*. 2009;3(1):16–20.

49. Ferrari M. Cancer nanotechnology: Opportunities and challenges. *Nature Reviews Cancer*. 2005;5(3):161–171.

50. Jain M, Fiddes IT, Miga KH, et al. Improved data analysis for the MinION nanopore sequencer. *Nature Methods*. 2016;13(7):581–586.

51. Jokerst JV. Nano–biosensors: A new wave of diagnostic sensors. *Analytical Chemistry*. 2012;84(2):249–265.

52. Kang E, Jeong GS, Choi YJ, et al. Layer–by–layer assembly of biopolymer–based films for delivery of small molecules and live cells. *Journal of Controlled Release*. 2014;190:330–348.

53. Laszlo AH, Derrington IM, Ross BC, et al. Decoding long nanopore sequencing reads of natural DNA. *Nature Biotechnology*. 2014;32(8):829–833.

54. Murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nature Biotechnology*. 2014;32(8):773–785.

55. Wang J. Nanomaterial–based electrochemical biosensors. *Analyst*. 2008;133(7):855–865.

56. Whitesides GM. The “right” size in nanobiotechnology. *Nature Biotechnology*. 2005;23(1):10–11.

57. Elowitz MB, Leibler S. A synthetic oscillatory network of transcriptional regulators. Nature.2020;403(6767)335–338.

58. Endy D. Foundations for engineering biology. *Nature*. 2005;438(7067):449–453.

59. Gardner TS, Cantor CR, Collins JJ. Construction of a genetic toggle switch in *Escherichia coli*. *Nature*. 2000;403(6767):339–342.

Citation: Eskandar K. Revolutionizing biotechnology and bioengineering: unleashing the power of innovation. *J Appl Biotechnol Bioeng*. 2023;10(3):81–88. DOI: 10.15406/jabb.2023.10.00332

Copyright: ©2023 Eskandar

60. Gibson DG, Glass JI, Lartigue C, et al. Creation of a bacterial cell controlled by a chemically synthesized genome. *Science*. 2010;329(5987):52–56.

61. Gibson DG, Smith HO, Hutchison III CA, et al. Chemical synthesis of the mouse mitochondrial genome. *Nature Methods*. 2008;7(11):901–903.

62. Hutchison III CA, Chuang RY, Noskov VN, et al. Design and synthesis of a minimal bacterial genome. *Science*. 2016;351(6280):aad6253.

63. Keasling JD. Manufacturing molecules through metabolic engineering. *Science*. 2010;330(6009):1355–1358.

64. Lee JW, Na D, Park JM, et al. Systems metabolic engineering of microorganisms for natural and non–natural chemicals. *Nature Chemical Biology*. 2012;8(6):536–546.

65. Peccoud J, Blauvelt MF, Cai Y, et al. Targeted development of registries of biological parts. *PLoS ONE*. 2008;3(7):e2671.

66. Segall–Shapiro TH, Nguyen PQ, Dos Santos ED, et al. Engineered enzymes as reporters for the direct detection of biomolecules *in vitro*. *Nature Communications*. 2018;9(1):1208.

67. Badylak SF, Weiss DJ, Caplan A, et al. Engineered whole organs and complex tissues. *The Lancet*. 2011;377(9779):403–415.

68. Caplan AI. Adult mesenchymal stem cells for tissue engineering versus regenerative medicine. *Journal of Cellular Physiology*. 2007;213(2):341–347.

69. Langer R, Vacanti JP. Tissue engineering. *Science*. 1993;260(5110):920–926.

70. Liu H, Ye Z, Kim Y, et al. Generation of endoderm–derived human induced pluripotent stem cells from primary hepatocytes. *Hepatology*. 2018;67(1):660–674.

71. Rouwkema J, Khademhosseini A. Vascularization and angiogenesis in tissue engineering: Beyond creating static networks. *Trends in Biotechnology*. 2016;34(9):733–745.

72. Schurr MO, Schulz RM, Weimann L, et al. Skin substitutes: Bioengineered alternatives to promote wound healing. *Advanced Healthcare Materials*. 2020;9(11):1901906.

73. Takebe T, Sekine K, Enomura M, et al. Vascularized and functional human liver from an iPSC–derived organ bud transplant. *Nature*. 2015;499(7459):481–484.

74. Ali H, Khan E, Sajad MA. Phytoremediation of heavy metals—Concepts and applications. *Chemosphere*. 2013;91(7):869–881.

75. Atlas RM, Hazen TC. Oil biodegradation and bioremediation: A tale of the two worst spills in US history. *Environmental Science & Technology*. 2011;45(16):6709–6715.

76. Dvořák P, Nikel PI, Damborský J, et al. Bioremediation 3.0: Engineering pollutant–removing bacteria in the times of systemic biology. *Biotechnology Advances*. 2017;35(6):845–866.

77. Pérez–Pantoja D, Donoso R, Agulló L, et al. Genomic analysis of the potential for aromatic compounds biodegradation in Burkholderiales. *Environmental Microbiology*. 2012;14(4):1091–1117.

78. Pulz O, Gross W. Valuable products from biotechnology of microalgae. *Applied Microbiology and Biotechnology*. 2004;65(6):635–648.

79. Salt DE, Blaylock M, Kumar NPBA, et al. Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants. *Bio/Technology*. 1995;13(5):468–474.

80. Strejcek M, Smrhova T, Junkova P, et al. Bacterial community assembly in contaminated environments: The roles of dispersal mode, time, and deterministic microbial niche. *Environmental Microbiology*. 2018;20(3):1158–1170.

81. Vymazal J. Emergent plants used in free water surface constructed wetlands: A review. *Ecological Engineering*. 2013;61:582–592.

82. Atala A. Regenerative medicine: Beyond the promise. *Journal of Tissue Engineering and Regenerative Medicine*. 2019;13(11):1825–1826.

83. Dominici M, Le Blanc K, Mueller I, et al. Minimal criteria for defining multipotent mesenchymal stromal cells. In International Society for Cellular Therapy position statement. *Cytotherapy*. 2006;8(4):315–317.

84. Gao G, Vandenberghe H, Wilson JM. New recombinant adeno–associated viruses for gene therapy. *Nature Reviews Genetics*. 2021;22(1):1–20.

85. Ginn SL, Amaya AK, Alexander IE, et al. Gene Therapy Clinical Trials Worldwide Database. Gene therapy clinical trials worldwide to 2017: An update. *The Journal of Gene Medicine*. 2018;20(5):e3015.

86. Kobayashi T, Yamaguchi T, Hamanaka S, et al. Generation of rat pancreas in mouse by interspecific blastocyst injection of pluripotent stem cells. *Cell*. 2018;172(4):1–15.

87. Liu S, De Castro LF, Jin P, et al. Manufacturing differences affect human bone marrow stromal cell characteristics and function: Comparison of production methods and products from multiple centers. *Science Reports*. 2018;8(1):1–14.

88. Lux CT, Pattabhi S, Berger M, et al. Genome editing in human cells using CRISPR–Cas9: Progress and challenges. *Biomolecules* 2019;9(12):1–26.

89. Naso MF, Tomkowicz B, Perry WL, et al. Adeno–associated virus (AAV) as a vector for gene therapy. *BioDrugs*. 2017;31(4):317–334.

90. Skardal A, Murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nature Reviews Methods Primers*. 2020;1(1):1–24.

91. Takahashi K, Yamanaka S. Induction of pluripotent stem cells from mouse embryonic and adult fibroblast cultures by defined factors. *Cell*. 2006;126(4):663–676.

92. Uygun BE, Soto–Gutierrez A, Yagi H, et al. Organ reengineering through development of a transplantable recellularized liver graft using decellularized liver matrix. *Nature Medicine*. 2017;23(1):64–71.

93. Adrio JL, Demain AL. Microbial enzymes: Tools for biotechnological processes. *Biomolecules*. 2014;4(1):117–139.

94. Gupta AK, Bharimalla AK, Deshmukh K, et al. Bioplastics: Current scenario and challenges. *Journal of Macromolecular Science, Part C: Polymer Reviews*. 2015;55(6):749–780.

95. Huang L, Shi M, Wang Q, et al. Bioremediation of oil–contaminated soil: Microorganisms' journey from bench to field application. *Critical Reviews in Biotechnology*. 2020;40(2):164–182.

96. Kourmentza C, Plácido J, Venetsaneas N, et al. Recent advances and challenges towards sustainable polyhydroxyalkanoate (PHA) production. *Bioengineering*. 2017;4(2):55.

97. Lynd LR, Liang X, Biddy MJ, et al. Cellulosic ethanol: Status and innovation. *Current Opinion in Biotechnology*. 2017;45:202–211.

98. Pandey VC, Singh N, Singh R, et al. Sustainable bioremediation of organic compounds contaminated soil using plant, fungi, and bacterial species. *Frontiers in Microbiology*. 2018;9:1–21.

99. Patel AK, Singhania RR, Pandey A, et al. Industrial enzymes: Present status and future perspectives for bioprocess development. *Renew Sustainable Energy Reviews*. 2018;90:254–265.

100. Tester M, Langridge P. Breeding technologies to increase crop production in a changing world. *Science*. 2010;327(5967):818–822.

101. Wolt JD, Wang K, Yang B. The regulatory status of genome–edited crops. *Plant Biotechnology Journal*. 2016;14(2):510–518.

102. Cheng H, Yi H, Huang Y, et al. Biomimetic and bioinspired nanomaterials for sustainable solar energy conversion. *Chemical Society Reviews*. 2016;45(18):5177–5192.

Citation: Eskandar K. Revolutionizing biotechnology and bioengineering: unleashing the power of innovation. *J Appl Biotechnol Bioeng*. 2023;10(3):81–88. DOI: 10.15406/jabb.2023.10.00332

103. Meyers MA, Chen PY, Lin AYM, et al. Biological materials: Structure and mechanical properties. *Progress in Materials Science*. 2011; 53(1):1–206.

104. Pfeifer R, Lungarella M, Iida F. The challenges ahead for bio–inspired 'soft' robotics. *Communications of the ACM*. 2014;58(9):76–87.

105. Shadwick RE, Lauder GV. Fish biomechanics. *Annual Review of Fluid Mechanics*. 2006;38:193–224.

106. Srinivasan V, Chen G, Barteau M, et al. Bio–inspired materials for solar energy conversion. *Journal of Materials Chemistry*. 2012;22(41):21930–21949.

107. Zhang M, Xu D, Li Y. Bioinspired materials for water purification: A review. *Bioinspiration & Biomimetics*. 2019;14(1):011001.