

ROLE OF ARTIFICIAL INTELLIGENCE IN BIOTECHNOLOGICAL APPLICATIONS

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Abstract

From 19th century Artificial intelligence is used for various purposes in different applied fields. Across the diverse biotechnological applications artificial intelligence plays a crucial role where it represents human intelligence simulation. Artificial Intelligence is most promising technology for revolutionizing and transforming different areas such as genomics, healthcare, medicinal and pharmaceutical industry, bioprocess industry as well as production technology. Today it is need of time to use artificial intelligence to handle and analyze large massive data. Artificial Intelligence is required for bioprocessing, automation, data integration and biotechnological engineering.

Keywords: Artificial Intelligence, Biotechnological Applications, Applied Fields.

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Introduction

Biotechnology is a multidisciplinary field that involves the use of living organisms, biological systems, or derivatives to develop products and technologies for various sectors, including healthcare, agriculture, and environmental science. It encompasses techniques such as genetic engineering, cloning, and fermentation, and plays a critical role in areas like drug development, vaccine production, and crop improvement. The convergence of artificial intelligence (AI) and biotechnology catalyses a transformative shift in scientific discovery and healthcare. It explores the multifaceted impact of AI on various domains within biotechnology, highlighting its potential to reshape drug discovery, biomedical imaging, predictive analytics, and healthcare delivery. In AI-driven drug discovery, machine learning and deep learning algorithms expedite compound screening, molecular modelling, and compound design. AI-powered biomedical imaging enhances disease detection and interpretation accuracy across modalities such as X-rays, MRIs, and histopathology slides. (Izankar 2024) There are a number of application areas where the ability to use big data will become a key factor, including drug discovery, drug recycling, drug safety, functional and structural genomics, proteomics, pharmacogenetics, and pharmacogenomics, among other and to handle this artificial intelligence algorithms are used. (Oliveira 2019). AI and ML are reshaping traditional methods by improving the accuracy, efficiency, and scalability of complex biochemical processes. Key advancements include AI-driven genome sequencing, protein structure prediction, drug discovery, and bioprocess optimization. In biochemistry, AI enhances the analysis of high-throughput data, enables better prediction of chemical reactions, and supports metabolomics and proteomics studies. The role of AI in personalized medicine, including disease diagnostics, pharmacogenomics, and precision treatments, is also highlighted. While AI and ML promise unprecedented opportunities, challenges such as data quality, mode

interpretability, and ethical concerns remain significant hurdles. Looking forward, AI-driven innovations are poised to further transform biotechnology, fostering interdisciplinary collaborations and sustainable biochemical practices (Jumper J 2021).

Artificial Intelligence in Plant Improvement Methods

AI is also crucial in agriculture and plant biotechnology as it drives progress in crop breeding, enhances crop output, monitors plant health, and promotes sustainable agriculture through precision farming and resource optimization. This book chapter provides a comprehensive examination of the synergistic combination of artificial intelligence and biotechnology (Kumaret-al2025).

Principal component analysis, cluster analysis, additive main effects and multiplicative interactions (AMMI), and genotype plus genotype × environment interaction biplot (GGE) are multivariate procedures enabling examination of multidirectional aspects of the GEI by imaging the response of a genotype in an *E*-dimensional space. Multivariate stability analyses are more powerful and precise than univariate approaches. However, these are complex methods that do not provide a simple measure of yield stability for a reliable ranking of genotypes.

Machine learning techniques are able to manage large amounts of data in various areas of plant breeding, which can lead to more accurate results and better interoperation than classical statistical methods. Artificial neural networks can be used for pattern recognition, nonlinear regression, and classification purposes in plant tissue culture studies because they can handle binary, continuous, categorical, and fuzzy datasets. The present review can give an overview of applications of machine learning (Niazian, M 2020)

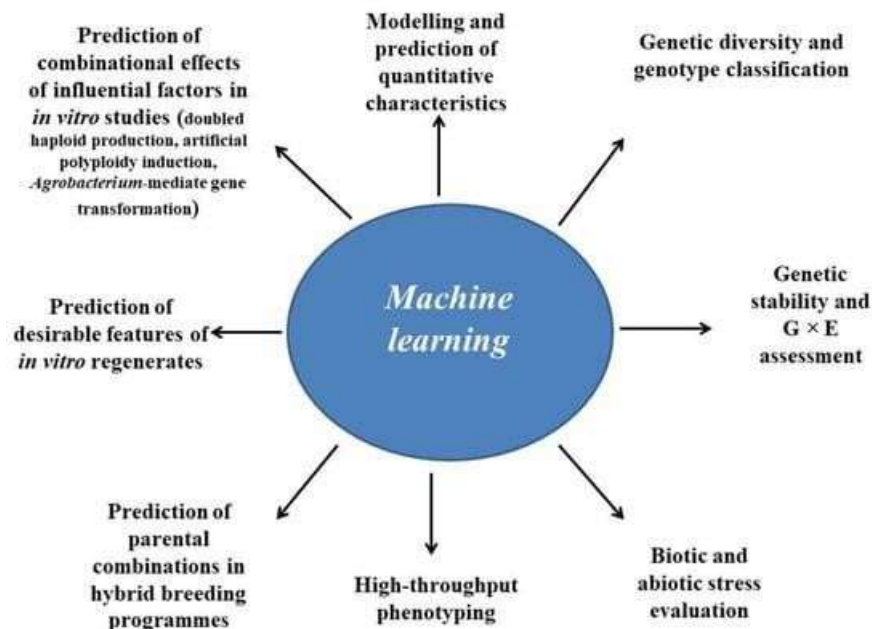


Figure 1 Potential applications of machine learning techniques in classical and modern plant breeding. (Niazian 2020)

Role of Artificial Intelligence in IVF

Integrating artificial intelligence (AI) in in vitro fertilization (IVF) laboratories represents a significant advancement in reproductive medicine. AI tools such as machine learning and deep

learning enhance quality control, improve accuracy, and increase efficiency in tasks like embryo and sperm selection. By automating traditionally manual processes, AI reduces human error and variability, thus supporting higher success rates for IVF treatments. (Hew 2024). AI-based methods offer automated, objective, more efficient, and speedier tools for optimally evaluating and selecting human embryos, by correctly and reliably identifying ‘key developmental hallmarks of embryo viability’ to accurately grade and rank embryos, thereby assisting in the decision-making process to transfer/freeze them (Tamir 2023). compared computational models for the prediction of IVF/ICSI (intra-cytoplasmic sperm injection) outcomes with surgically retrieved spermatozoa. Their dataset was comprised of 113 exemplars, derived from patients who underwent IVF/ICSI. As input features they used maternal age, sperm retrieval technique, type of spermatozoa, type of male factor, and output intrauterine pregnancy, being modeled by using linear and quadratic discriminant function analysis, logistic regression, and neural computation (Siristatidis). Choosing the best embryo for transfer during in vitro fertilization (IVF) is a difficult and subjective task. Embryologists currently examine embryos under a microscope. However, this method can be inconsistent and does not always identify the embryo most likely to result in a pregnancy. This review examines how Artificial Intelligence (AI) is being used to help solve the dilemma. AI can analyze thousands of images and videos of developing embryos to spot subtle signs of health that humans might miss. It acts as a powerful assistant to embryologists. Mainly, it helps them make more consistent, data-driven choices. Indeed, AI shows great promise in making IVF more efficient and reducing the workload for clinic staff (Mrugacz 2026).

Role of Artificial Intelligence in Genetic Engineering

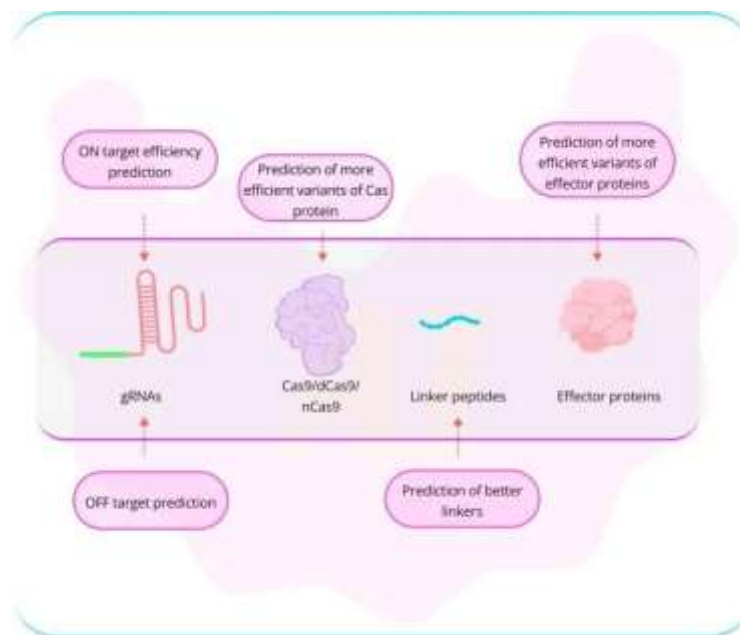


Figure 2 2 Challenges associated with genome editing using CRISPR technology.

One of the most acknowledged challenges in CRISPR-based genome editing is the efficiency of on-target editing and the potential off-target effects. Researchers have explored the use of AI-based tools, such as AlphaFold2, for the prediction of more effective Cas variants and effector

proteins. While designing linker peptides is currently not a major obstacle, it remains crucial when connecting an effector protein to a Cas nuclease.(Dixit 2024)

Using AI in GED is imperative and holds the promise to revolutionize the healthcare sector. CRISPR-based editing technologies like CRISPR/Cas9 allow for precise and targeted editing of the genetic code of organisms, which is a major breakthrough in biotechnology. However, AI's integration with CRISPR, improves the overall GED pipeline, providing new insights, capabilities, and opportunities for manipulating and understanding the genetic code. The recent advances in multi-omics technologies that can produce big data from different sources, such as genes, RNA, proteins, and DNA modifications, have made AI necessary for analyzing medical information (Dixit 2023) Prime editing is an emerging technique that utilizes reverse transcription to insert programmed sequence modifications into DNA sequences . It is an adaptable GED tool, capable of making a wide range of genetic changes, but achieving high editing efficiency and product purity necessitates PED guide RNA (pegRNA) experimental optimization

Medicinal Applications of Artificial Intelligence

According to the history books, the earliest applications of artificial intelligence in the medical field occurred predominantly in the 1960s and 1970s (the term itself having been coined by John McCarthy in 1955 . On a broader scale, early theorists like Alan Turing . t this time, there are a small but growing number of AI health care products on the market. Most current offerings appearing to be for use in patient diagnosis, and many seem specifically to supplement the abilities of existing imaging modalities. One example is the IDx-DR software program (IDx, LLC, Coralville, IA, USA) recently approved by the United States Food and Drug Administration (FDA), which uses an AI algorithm to analyze images of the eye taken with a retinal camera to spot symptoms . In response to a study evaluating the use of deep learning algorithms for the detection of lymph node metastases in women with breast cancer(Becker 2019)

In recent years, AI solutions have shown to be capable of assisting radiologists and clinicians in detecting diseases, assessing severity, automatically localizing and quantifying disease features, or providing an automated assessment of disease prognosis. AI for MI has received extraordinary attention in 2020, as attested by a multitude of interdisciplinary projects attempting to blend AI technologies with knowledge from MI in order to combat COVID-19. A keyword search combining AI and MI revealed 2,563 papers in 2019, while 2020 has seen more than twice the number of such papers. Of these publications, 827 are related to COVID-19, indicating that COVID-19 has accelerated the development of AI in MI. (Born et-al 2021). AI can also help doctors monitor patients' progress and adjust treatments as necessary. This can be especially helpful in cases where patients are receiving complex treatments, such as chemotherapy. AI can also help doctors develop new treatments for diseases. (Rezei 2023)

Artificial Intelligence in Bioprocess Technology

AI technologies (ANN, SVM, FL, GA and PSO) are applicable in bioprocess control and optimization, as well as their advantages and limitations. The technologies of modeling and optimizing the whole bioprocess have matured. (Cheng et-al 23)

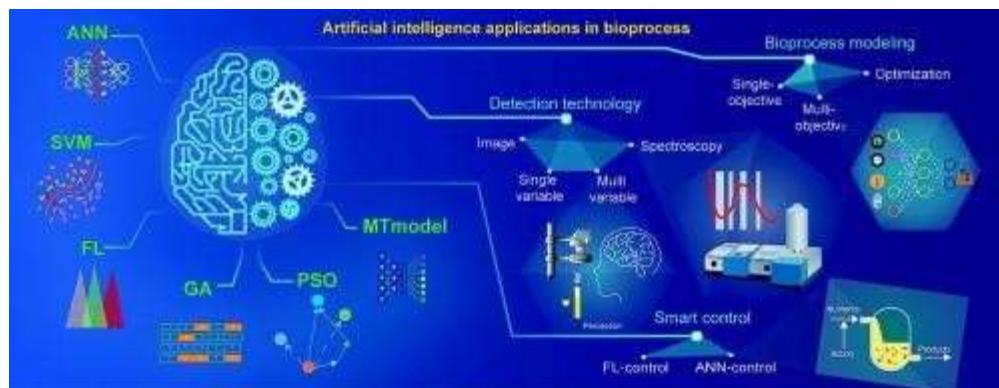


Figure3 AI guided Bioprocess optimization(Cheng et-al23)

AI enhances biotechnology manufacturing efficiency and cost. This is a transition period where biotechnology production may be transformed the biological materials and automation. These advancements will make manufacturing more straightforward, provide better quality, and allow faster development of biotechnology products. (Mehta et al). Artificial intelligence can be applied in different automation process which involves anaerobic digestion, Thermochemical conversion composting (ANN, RF algorithm, AI, ML models), microalgae identification, fungi bioprocessing, waste water treatment (LSTM), bioprocess optimization (ANN, multiobjective GA), monitoring and control, biomolecule interactions (ML techniques), Techno economic analysis and life cycle assessment. (Mehta 2024)

An artificial intelligence strategy can be used to depict and manage a bioreactor containing a population of cells in real conditions. This requires merging the domains of artificial intelligence and cellular intelligence in order to formulate an integrated intelligence-centred strategy that is more faithful to physiology compared to the conventional approaches currently in use. (Shah 2025) Complexity spans from Level 0 (no autonomy) through Level 1 (research assistance), Level 2 (partial autonomy), Level 3 (conditional autonomy), Level 4 (highly-autonomous research), to Level 5 (AI scientist). Currently, most bioprocess automation operates at Levels 1–2 with significant human oversight, as bioprocesses involve complex multiscale experimentation, high experimental uncertainty, safety considerations, and regulatory requirements. (Helleckes 26) The optimal balance between autonomy and human decision-making, therefore, needs to be discussed for future bioprocess applications. An important stepping stone toward functional SDLs is the fusion of lab automation with large language models (LLMs) and other tools in agentic frameworks (e.g. Coscientist [Boiko] and ChemCrow [Bran] in chemistry), which are able to translate high-level goals into executable plans, navigate documentation, and orchestrate whole experimental workflows.

Conclusion

Big data, artificial intelligence, and machine learning will become instrumental in all future biotechnology research. More and more researchers in biotechnology will have to become aware of the methods required to deal with large amounts of data and to include in their research teams people with the ability to integrate, organize, and explore this data. Researchers specialized in bioinformatics will become a key element in any biotechnology research team but, in many cases, the identification of opportunities will depend on the awareness about this topic of the biotechnology researchers themselves. This article aims at raising this awareness and, in this way, contributing to the development of this area of science. (Oliveira 2019). This review emphasized

promising crucial role of Artificial intelligence algorithms for handling massive data as well as diagnosis, treatment of patients, drug discovery. Different artificial intelligence tools used for Biotechnological applications are deeppvariant,alphafold(for genomics,ptoreomics),biopython,tensorflow (Bioinformatics), atomwise,chemprop(Drug discovery),cell profiler ,deepcell(Microscopy),Maxent , EvoNet(Evolutionary studies),COBRA toolbox, Cytoscape (System Biology),

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