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Applications of Artificial Intelligence in Biotechnology: Current Trends and Future Prospects

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Abstract: Artificial intelligence (AI) is becoming an important tool in biotechnology research because it can analyse large and complex biological datasets more quickly than traditional approaches. Applications include drug discovery, genomics, protein-structure prediction, disease diagnosis, personalised medicine, and biomanufacturing. This paper reviews the main uses of AI in biotechnology and examines its possible benefits, including faster research, improved prediction, automation, and reduced development costs. It also discusses limitations such as poor-quality data, algorithmic bias, lack of explainability, privacy risks, and difficulties in validating AI-generated results. The review argues that AI should be treated as a decision-support technology rather than a replacement for biological expertise. Responsible adoption requires high-quality datasets, human oversight, transparent methods, secure data governance, and appropriate regulation.

The paper concludes that AI is neither completely good nor completely bad in biotechnology. Its value depends on how it is designed, tested, and used. When combined with laboratory validation and ethical safeguards, AI can strengthen biotechnology research and support the development of safer and more effective solutions.

Keywords: artificial intelligence, biotechnology, machine learning, drug discovery, genomics, precision medicine, ethics, data privacy.

I. INTRODUCTION

Biotechnology uses biological systems, organisms, or biological information to develop products and solve problems in healthcare, agriculture, food production, and the environment. Modern biotechnology increasingly generates data from DNA sequencing, protein analysis, medical imaging, electronic health records, and laboratory experiments. The size and complexity of these datasets make manual analysis slow and difficult. AI, including machine learning and deep learning, provides methods for identifying patterns, making predictions, and supporting research decisions. The integration of AI with biotechnology has attracted attention because it may improve the efficiency of research and development. Recent reviews describe applications in drug discovery, genomics, medical imaging, and personalised medicine, but also emphasise data quality, transparency, explainability, and ethical governance as major concerns. [1,2] This paper reviews the question: How can AI improve biotechnology research, and what challenges must be addressed for its responsible use?

A. Background

AI refers to computer systems that perform tasks commonly associated with human intelligence, such as learning from data, recognising patterns, and generating predictions. Machine learning algorithms learn relationships from examples, while deep-learning models use multiple computational layers to identify complex patterns. In biotechnology, these methods can process biological sequences, molecular structures, experimental measurements, and clinical information.

Unlike many traditional datasets, biological data are highly variable and interconnected. A prediction that appears accurate in one dataset may not work in another population, laboratory, or biological condition. Therefore, AI-based findings require careful validation through independent datasets, laboratory experiments, and, where appropriate, clinical studies.

B. Objectives

The objectives of this paper are to:

• Explain the role of AI in biotechnology research.

• Identify major applications in drug discovery, genomics, diagnosis, and personalised medicine.
• Examine the benefits of AI-assisted biotechnology research.
• Discuss technical, ethical, legal, and social limitations.
• Suggest principles for responsible and reliable implementation.

II. LITERATURE REVIEW

The literature indicates that AI can support several stages of biotechnology research. In drug discovery, it is used for target identification, molecular screening, prediction of molecular interactions, drug design, and drug repurposing. A recent review reports that AI can improve predictive capability and reduce the time and cost associated with parts of drug development, while noting that data quality, interpretability, and ethical policy remain substantial barriers. [2,3]

In genomics, AI can help classify genetic variants, identify patterns in gene-expression data, and support the study of disease mechanisms. In precision medicine, the combination of AI and multi-omics data may assist researchers in generating hypotheses and identifying treatment strategies. However, these applications depend on representative datasets and rigorous validation because genetic and clinical data can differ across populations. [1]

Health-related AI also raises questions about autonomy, safety, transparency, accountability, equity, and sustainability. The World Health Organization recommends an ethics and governance approach that protects human autonomy, promotes well-being and public interest, supports transparency, ensures responsibility, advances inclusiveness, and encourages sustainable systems. [4]

Table 1. Summary of literature on AI applications in biotechnology, drug discovery, and healthcare ethics.

Section	Key scholars/source	Core concepts	Main contribution	Relevance
AI in biotechnology	Bhushan et al. [1]	Multimodal AI; data quality; explainability	Maps opportunities and barriers across biotechnology	Provides broad framework
AI in drug discovery	Bassey et al. [2]	Screening, molecular modelling, clinical-trial support	Describes faster prediction and lower development burden	Supports benefits and limitations
Drug research and development	Recent review [3]	Drug repurposing and knowledge graphs	Shows how existing compounds can be assessed more efficiently	Illustrates practical application
AI ethics in health	WHO [4]	Autonomy, safety, transparency, equity	Provides governance principles	Guides responsible use

III. SYNTHESIS & THEORETICAL GAP

The reviewed literature agrees that AI is valuable because it can process biological information at a scale that is difficult to achieve manually. Nevertheless, technical capability does not automatically produce scientific reliability. The theoretical gap lies in connecting AI performance with responsible biotechnology practice: a useful model must be accurate, reproducible, interpretable, secure, and relevant to the population or biological system being studied.

Table 1: Evaluation of AI Applications, Limitations, and Mitigation Strategies in Biotechnology.

Domain	Strength	Limitation	How to address it	What this paper addresses
Drug discovery	Rapid screening and prediction	False positives; weak biological transfer	Independent datasets and laboratory validation	Reliability of AI-assisted decisions
Genomics	Pattern detection in large datasets	Bias and privacy risks	Representative data, consent, secure governance	Equity and data protection
Clinical and personalised medicine	Patient-specific predictions	Limited explainability and accountability	Human oversight and transparent reporting	Ethical implementation
Biomanufacturing	Process optimisation and automation	Changing conditions and model drift	Continuous monitoring and recalibration	Long-term model governance

IV. METHODOLOGY

This paper uses a qualitative narrative literature-review methodology. Published review articles and guidance documents were selected to identify recurring applications, benefits, risks, and governance requirements. The analysis is based on secondary sources rather than laboratory experimentation or a human-participant survey.

1) Sample size: Five major source documents were examined for this student review.
2) Sample area/geography: International biotechnology and health research.
3) Method: Comparative thematic analysis.
4) Qualitative/quantitative: Qualitative.
5) Questionnaire: Not used.
6) Orientation: Methodological and conceptual.

V. APPLICATIONS OF AI IN BIOTECHNOLOGY

1) Drug discovery: AI can prioritise biological targets, screen candidate molecules, estimate molecular properties, and assist drug repurposing. These capabilities may reduce the number of compounds requiring early experimental testing, but predictions must be confirmed in the laboratory. [2,3] Genomics and genetic research: Machine-learning models can analyse DNA and RNA data, classify variants, and identify relationships between genes and disease. The main concerns are dataset bias, privacy, and the risk of overstating correlations as causal biological explanations.
2) Diagnosis and personalised medicine: AI can support analysis of medical images and clinical information and may help match treatments to patient characteristics. Such systems should assist qualified professionals because errors can affect patient safety and because model performance may vary between hospitals and populations.
3) Biomanufacturing: AI can monitor production conditions and identify patterns associated with quality or process failure. Continuous monitoring is necessary because biological processes can change over time.

VI. BENEFITS AND CHALLENGES

The main benefits are speed, scalability, automation, improved pattern recognition, and the possibility of reducing research costs. AI can help scientists focus on promising hypotheses instead of examining every possible combination manually. It can also combine different forms of data, such as genomic, chemical, and clinical information.

The main challenges are equally important. Incomplete or poorly labelled data can produce unreliable outputs. A black-box model may provide a prediction without a scientifically understandable reason. Genetic and health information requires strong privacy protection. Bias in training data can make systems less accurate or less fair for underrepresented groups. Finally, legal responsibility can be unclear when researchers rely on an AI-generated recommendation.

VII. RESPONSIBLE IMPLEMENTATION

Responsible use should follow a human-in-the-loop model. Researchers should define the purpose of the system, document the data used, test performance on independent datasets, report uncertainty, and validate important predictions experimentally. Sensitive data should be collected with appropriate consent and protected through secure storage and controlled access.

Institutions should also establish accountability: a named researcher or organisation must remain responsible for decisions influenced by AI. Models should be monitored after deployment, and their performance should be reassessed when data, populations, instruments, or laboratory conditions change. These practices are consistent with the WHO emphasis on autonomy, safety, transparency, accountability, inclusiveness, and sustainability. [4]

VIII. CONCLUSION

Artificial intelligence represents a transformative paradigm in biotechnology, offering key capabilities across drug discovery, genomics, diagnosis, personalized medicine, and biomanufacturing. However, AI cannot replace experimental evidence or biological expertise.

Key challenges—including data quality, algorithmic bias, privacy risks, lack of explainability, and regulatory oversight—must be addressed before AI-generated insights are deployed in clinical or high-stakes settings. AI provides maximum value when used as a decision-support tool alongside laboratory validation and transparent scientific oversight.

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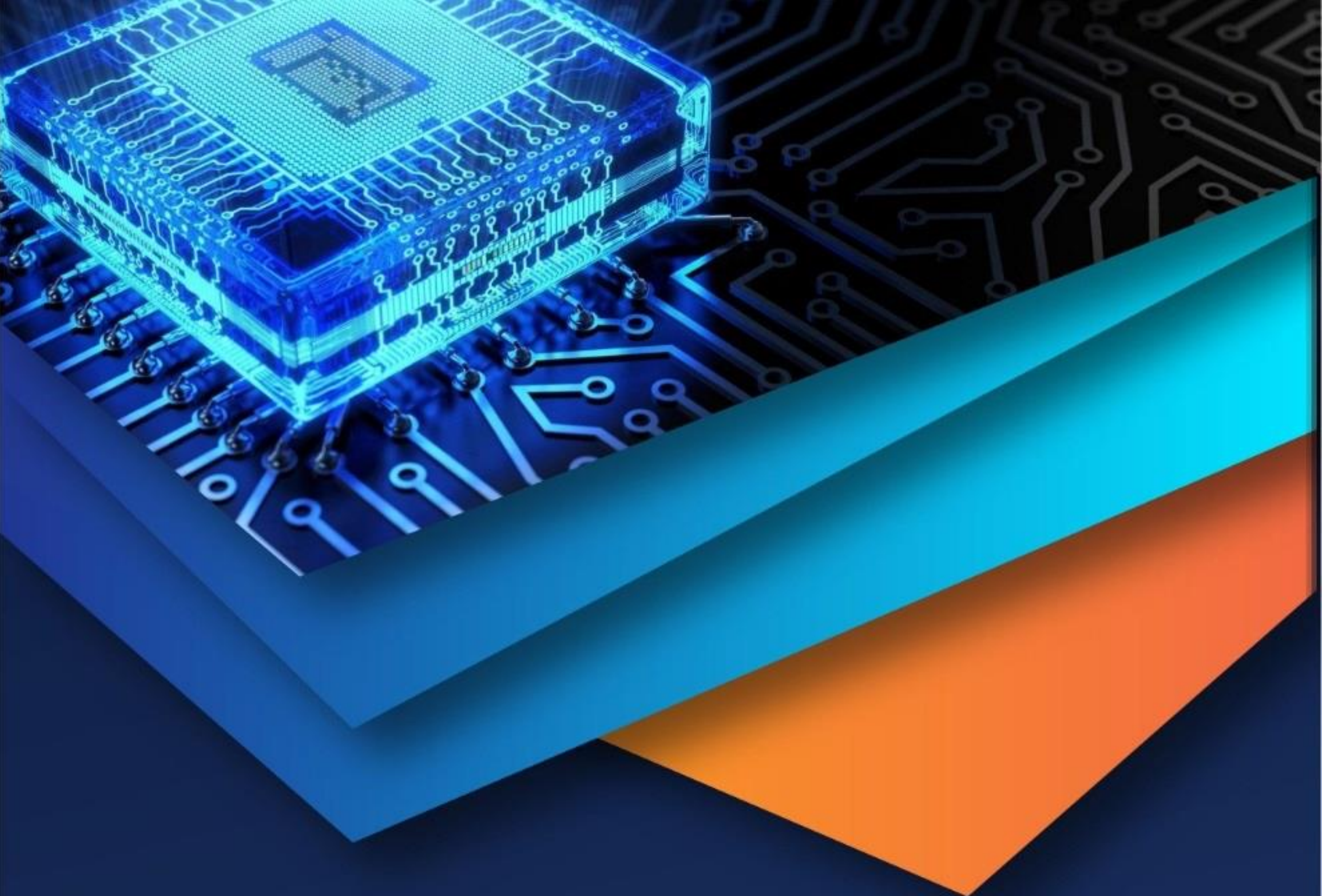

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