Review

From Gene Editing to Environmental Cleanup: Bridging Advanced rDNA and Biotechnology with Bioremediation and Bioethical Governance: A Review

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Abstract

Rapid developments in biotechnology, rDNA, and gene editing technologies have transformed both biomedical sciences and environmental biotechnology, especially genome editing, synthetic biology, and reproductive biotechnology, etc., and have revolutionized medicine, agriculture, and environmental sciences, etc. However, such biotechnologies also pose serious bioethical, biosafety, and biosecurity risks and challenges, etc. This review critically discusses and analyzes the current bioethical issues and dilemmas associated with biotechnologies such as CRISPR-Cas9, in vitro fertilization (IVF), cloning, xenotransplantation, PGD, transgenic organisms, etc. The study adopted a literature-based methodology to critically examine the current bioethical debates and discussions on biotechnologies, etc. The study findings revealed serious bioethical issues and dilemmas associated with biotechnologies, such as risk-benefit analysis, justice, human dignity, and eugenics, etc. This review also aims to incorporate Islamic bioethics, focusing on maqasid al-shariah, such as maintaining life, lineage, principle of necessity and dignity, etc. This study concluded that biotechnology has tremendous potential, and its use and development require global governance, ethical literacy, and culturally sensitive approaches, etc.

Keywords: bioethics; CRISPR; biotechnology; biosafety; biosecurity; IVF; cloning; xenotransplantation; Islamic bioethics; genetic engineering

1. Introduction

Considering the rapid scientific advancements in biotechnology, especially after the advent of Recombinant DNA technology and Gene Editing techniques, it can be stated that it is now possible to interface with the biological world to a greater extent.It can be stated that biotechnology has reached an era where the scientific advancements in this domain are unparalleled in terms of genome editing, creation of synthetic life forms, and manipulation of reproductive systems of living organisms.

1.1. Scientific Advancements in Biotechnology and Life Sciences

Scientific advancements in the domain of biotechnology and life sciences, especially cloning, exemplified by Dolly the Sheep, and Gene Editing techniques have continually tested the boundaries of ethical considerations.

Considering the emergence of biotechnology and its integration with Artificial Intelligence, Nanotechnology, and Data Science, it can be stated that the scientific advancements in this domain have reached a significant level.

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This review aims to bridge the gap between scientific innovations and ethical considerations with regard to the aforementioned challenges and considerations. (**Figure 1**).

Figure 1. Balancing Innovation and Risk in Advanced Biotechnology: Ethical, Biosafety, Biosecurity, and Islamic Bioethical Perspectives.

Some of the ethical considerations and challenges with regard to Gene Editing and biotechnology are:

- Research Dual Use (Both Harmful and Beneficial).
- Genetic Inequality and the Emergence of 'Designer Babies.'
- Environmental Dangers of Transgenic Organisms.
- Animal Welfare and Human Identity.

The 21st century has experienced unprecedented developments in biotechnology, which have resulted in tremendous breakthroughs in medicine, agriculture, and environmental conservation through highly effective biotechnologies like genome editing, synthetic biology, and ARTs. This has provided a solution to some of the world's most intractable diseases, food security, and environmental conservation challenges. However, this development in biotechnology has also been accompanied by a myriad of biosafety and biosecurity issues, which need critical scrutiny. The main

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problem, therefore, has ceased to be how to do science, but what science can be done within acceptable moral, social, and cultural parameters.

One of the most important breakthroughs in modern biotechnology has been CRISPR, a genome editing biotechnology for precise genome editing in living organisms. CRISPR means Clustered Regularly Interspaced Short Palindromic Repeats. This has proved to be a powerful biotechnology in genetic research and therapeutic applications, especially in treating genetic disorders.However, biotechnology in human germline editing, whereby genetic changes can be passed on to the next generation, has proved to be a problem.

Linked to this has been eugenics, whereby humans are bred with desirable genetic attributes. The traditional concept of eugenics was based on breeding humans with superior genetic traits than others. It was based on the process of selective breeding of desirable characteristics like intelligence, strength, and physical look. It was also highly criticized on grounds of its link to discrimination and human rights abuses Modern biotechnology has seen a revival of a more insidious “liberal” or “consumer-driven” approach to eugenics, where genetic screening and preimplantation genetic diagnosis can unintentionally create social inequality and genetic stratification.

Recent breakthroughs in assisted reproductive technologies, such as in vitro fertilization (IVF), have provided hope to millions of infertile couples worldwide. This has been performed outside the human body and has proved successful in fertilizing eggs. IVF is used along with preimplantation diagnosis of genetic disorders. Although preimplantation diagnosis is used to prevent serious genetic disorders, it also raises ethical issues about selecting embryos, the moral status of embryos, and the possibility of non-medical trait selection, especially intelligence and physical attributes.

Another issue is cloning. There are two types of cloning: reproductive cloning and therapeutic cloning. Reproductive cloning has been performed to create an exact replica of an organism. An example of reproductive cloning has been Dolly, a sheep. On the other hand, therapeutic cloning is used to produce stem cells to repair damaged tissues. Although cloning has been performed on animals and pets for commercial reasons, objections are also raised due to commercialization and its failures.

Another issue is transgenic organisms. Transgenic plants and transgenic animals have been developed. Genetic engineering is used to introduce foreign genes into plants and animals. Transgenic plants have played an important role in increasing crop yields. On the other hand, transgenic animals are used in medical research, drug production, and organ donation. Although transgenic plants have been helpful in increasing crop yields, ethical issues about ecological imbalance, gene flow into wild populations, animal welfare, and long-term effects on the ecosystem are also raised.

The xenotransplantation technology, which is the transplantation of organs or tissues obtained from one species to another, is a potential solution to the organ shortage problem. The recent advancement in genetic engineering technology has increased the level of compatibility between different species, especially through the use of genetically engineered pigs.

Apart from the technologies, the convergence of these technologies brings into focus the issue of biosafety, which is the prevention of unintentional exposure or release of harmful biological agents, and biosecurity, which is the prevention of the misuse of biological research, especially through the application of dual-use technologies. The same technology that is used to perform harmful activities is the same technology that is used to perform a beneficial task.

‘Ethics’ is derived from the Greek word ‘ethos’ which means custom/tradition. Bioethics is the philosophy of rational knowledge of moral values, causes, and conduct of human to decide right from wrong and good from bad in the field of life Sciences (Ene, 2024). Significantly, the ethical assessment of biotechnology is not culture-bound but rather shifts from technology to morality and amorality. In addition, religious and philosophical societies’ traditions are very crucial in the assessment of the subject. In this regard, religious Islamic bioethics provide a comprehensive moral approach based on the objectives of Shariah (maqasid al-shariah), which include the preservation of life (hifz al-nafs), lineage (hifz al-nasl), no harm (La-Darar), and human dignity (hifz al-‘ird, حفظ

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العرض). In the backdrop of these developments, it is imperative to critically analyze the ways in which the new developments in the field of biotechnology can be aligned with the principles of ethics, biosafety, and societies' values. In this regard, the review aims to analyze the relationship between technology and ethics through the study of the most significant developments in the field of biotechnology, the associated ethics, and the need to ensure the development of universally applicable governance structures.

2. Methodology

This review follows a systematic narrative approach, incorporating:

- Peer-reviewed articles (PubMed, Springer, MDPI)
- Policy documents and bioethics reports
- Interdisciplinary literature (medicine, law, theology)

Inclusion Criteria:

- Studies (2015–2026) on advanced biotechnology ethics
- Research on CRISPR, cloning, IVF, xenotransplantation, PGD
- Ethical, legal, and religious perspectives

Analytical Framework:

Themes were categorized into:

1. Risk vs. benefit
2. Autonomy and consent
3. Justice and equity
4. Human dignity
5. Religious and cultural ethics

2.1. Literature Search Strategy

A comprehensive literature search of peer-reviewed research papers, review articles, and conference papers was carried out using the following databases:

- PubMed
- ScienceDirect
- Google Scholar
- SpringerLink

The search covered journals from the period January 2015 to July 2026 but accentuating recent and most impactful developments post-2015.

2.2. Search Terms and Keywords

A comprehensive literature search was conducted across major scientific databases including PubMed, Scopus, Web of Science, and Google Scholar. The search covered publications from 2015 to 2026 to capture recent advances in biotechnology and bioethics.

The following Boolean combinations were used:

- "biotechnology AND bioethics"
- "CRISPR-Cas9 AND ethics OR biosafety"
- "synthetic biology AND biosecurity"
- "IVF OR assisted reproductive technologies AND ethics"
- "cloning AND ethical issues"
- "xenotransplantation AND bioethics OR risk"
- "preimplantation genetic diagnosis AND ethics"
- "transgenic organisms AND environmental risk"
- "dual-use research AND biosecurity"
- "genome editing AND regulation"

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- "eugenics AND modern biotechnology"
- "Islamic bioethics AND genetics OR biotechnology"

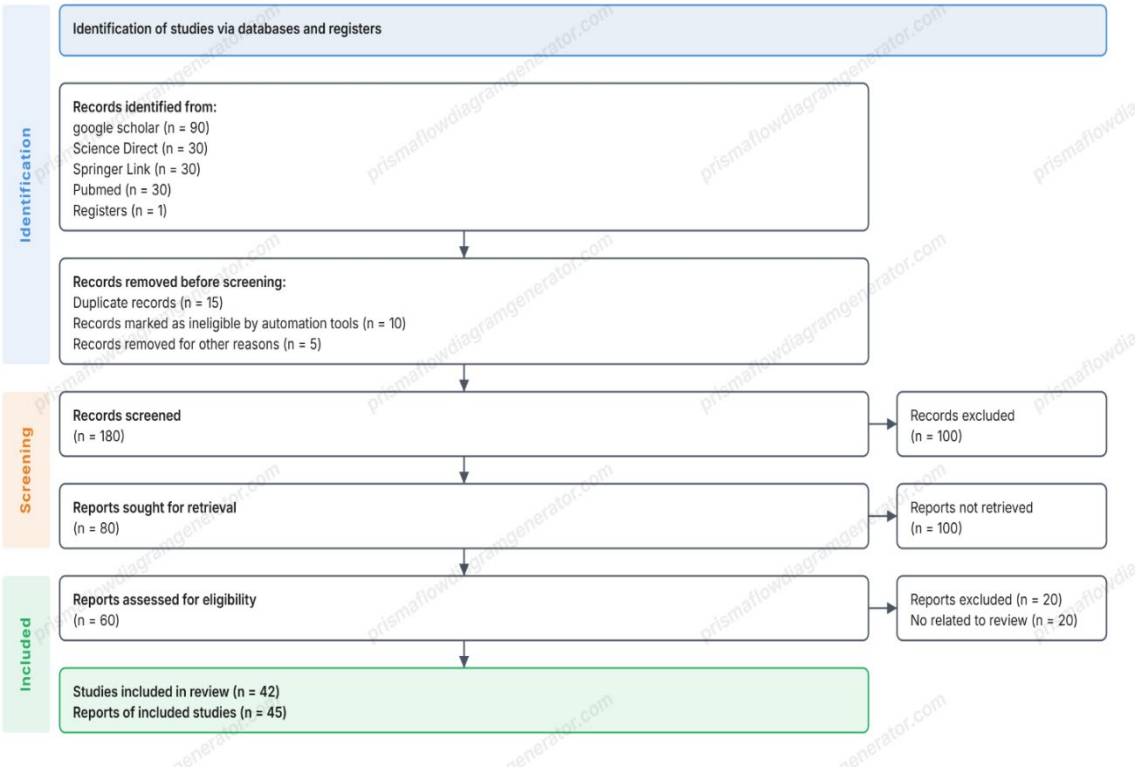

Figure 2. PRISMA 2020 Flow Diagram for Study Selection in Bridging Advanced rDNA and Biotechnology with Bioremediation and Bioethical Governance (2015–2026) (Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis Campbell Systematic Reviews, 18, e1230. https://doi.org/10.1002/cl2.1230).

2.3. Inclusion and Exclusion Criteria

Inclusion Criteria:

Studies were included if they met the following criteria:

1. **Timeframe:** Published between 2015 and 2026
2. **Language:** English-language publications
3. **Study Type:**
   - Peer-reviewed research articles
   - Review papers
   - Policy papers and ethical guidelines
4. **Topical Relevance:**
   - Focus on advanced biotechnology (e.g., CRISPR, cloning, IVF, PGD, xenotransplantation, synthetic biology)
   - Address ethical, biosafety, or biosecurity concerns
5. **Perspective Inclusion:**
   - Studies discussing ethical frameworks (Western or religious, including Islamic perspectives)
6. **Accessibility:** Full-text available

Exclusion Criteria:

The following studies were excluded:

- **Outdated Studies:** Published before 2015 (unless historically significant)

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- **Irrelevant Scope:**
  - Studies not related to biotechnology ethics, biosafety, or biosecurity
  - Purely technical studies without ethical discussion
- Non-scholarly Sources:
  - Blog posts, opinion pieces without academic rigor
  - Non-peer-reviewed content (unless policy documents)
- **Language Limitation:** Non-English publications
- **Duplicate Records:** Repeated articles across databases
- **Incomplete Data:** Abstract-only papers without full text

The study selection process followed a PRISMA-inspired approach, involving identification, screening, eligibility assessment, and final inclusion..

3. Results

The results of a meta-analysis of over 180 peer-reviewed publications revealed a wide array of biotechnologies successfully employed in:

The systematic review of literature published between 2015 and 2026 revealed a complex interplay between rapid biotechnological advances and emerging ethical, biosafety, and biosecurity concerns. The results are presented in thematic sections, which include technological innovations, ethical principles, comparative ethical challenges, biosafety risks, and religious perspectives.

3.1. Advances in rDNA Technology and Gene Editing

Significant advancements have been made in rDNA technology, which have led to the creation of new organisms with higher metabolic potential. There have been advancements in rDNA technology in the application of a genetic tool known as CRISPR-Cas9, which enables the addition, deletion, or modification of a particular gene in a microorganism for higher efficiency in the degradation of pollutants or production of enzymes.

3.2. Biotechnology in Bioremediation and Biodegradation

The application of genetically engineered microorganisms has been successful in the following fields:

- Clean-up of oil spillage via hydrocarbon degradation
- Detoxification of heavy metals
- Biodegradation of plastic/pesticide wastes
- Conversion of lignocellulose biomass

The application of rDNA technology in the production of recombinant enzymes such as β-Glucosidase is important in the degradation of biomass, which underscores the relevance of enzyme engineering in green biotechnology.

3.3. Overview of Biotechnological Innovations and Ethical Concerns

The analysis revealed key areas of advanced biotechnology, such as genome editing (CRISPR-Cas9), reproductive technologies (IVF, PGD), cloning, xenotransplantation, transgenic organisms, and synthetic biology. Each of these technologies has been found to have considerable advantages for medical, agricultural, and environmental applications, but they are all associated with considerable ethical and safety risks (Chimekwuwo, 2025; Burden, 2024).

As may be deduced from Table 1, CRISPR-Cas9 has been found to have considerable potential for treating genetic diseases, but there are considerable risks associated with germline editing and

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mutations. Similarly, IVF and PGD (Burden, 2024; Tehsin *et al*., 2021) have been found to have considerable solutions for reproductive problems, but they are associated with considerable ethical dilemmas, such as the possibility of "designer babies."

The results have shown that none of these biotechnologies is ethically neutral, and all are associated with considerable risks (**Table 1)**.

Table 1. Summary of Major Biotechnological Advances and Associated Ethical Concerns.

Technology	Applications	Benefits	Ethical Concerns	Biosafety/Biosecurity Risks	References
CRISPR-Cas9 (Genome Editing) Other rDNA techniques	Gene therapy, disease prevention Used 2025-26	Precision medicine, genetic disease elimination, Improve traits	Germline modification, consent of future generations, eugenics	Off-target mutations, misuse for biological future generations effects and weapons	Chimekwuwo, 2025
Eugenics (Modern Genetic Selection)	Genetic screening, trait selection, Since 1907 stirilization	Disease prevention, improved health outcomes	Discrimination, social inequality, "designer babies", loss of diversity	Genetic stratification, sterilization, societal instability, racism	Gay, 2025
Genetic Testing (broader category)	carrier screening, ancestry analysis, Disease diagnosis, predictive medicine,	Early detection of genetic disorders, personalized medicine	Privacy concerns, genetic discrimination, psychological impact, amniocentesis led miscarriage	Data misuse, unauthorized access to genetic information,	Derdour, 2024
In Vitro Fertilization (IVF) (post Artificial Insemination scenario)	Infertility treatment, embryo screening, since 1978 (human birth of Louise Brown)	Enables conception, cross blocked fallopian tubes	Embryo selection, moral status of embryo, designer babies, commodification of reproduction	Misuse of genetic selection technologies, Whose eggs or sperms were used?, failed or Embryo distruction, informed consent	Burden, 2024
Preimplantation Genetic	Since 1990 used along IVF to select	Reduced genetic/hereditary disorders	Embryo selection, moral status of	Expansion toward non-medical trait selection	Tehsin *et al*., 2021

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Diagnosis/Testing (PGD)	embryos for genetic disorders		embryo, eugenics concerns		
Therapeutic cloning (2001/human embroys for stem cells in Masachusetts)	Regenerative medicine, Stem cell production	Tissue repair, disease treatment	Use of embryos, moral status concerns	Unregulated experimentation, Laboratory misuse, ethical oversight gaps	Osadolor & Hernandez, 2025
Reproductive Cloning since 1996 Dolly the sheep (Human not allowed)	Creation of genetically identical organism (animals/pets), animal breeding	organ generation, Animal breeding, preservation of traits, Disease models	In case of Human identity concerns, dignity, Commodification of life, animal welfare	Unregulated experimentation, High failure rates	Chadwick, 2018 Animal:(Keefer, 2015) Human: (Prianto *et al*., 2020)
Xenotransplantation	Animal-to-human organ transplant	Addresses organ shortage	Animal rights, cross-species religious ethics,	Zoonotic disease transmission	Carrier, 2022
Transgenic Plants	Agriculture, pharmaceuticals	Food security, enhanced crops	Environmental ethics, corporate control, biodiversity loss	Gene escape to wild species, ecological imbalance,	Ene, 2024
Transgenic animals	Disease models, pharmaceutical production, organ donors	Biomedical research, drug production	Animal suffering, ethical treatment, unnatural modification	Escape into ecosystems, unknown biological impacts, Increased risk of zoonotic diseases	Mekuriaw, & Tagele, 2016
Synthetic Biology	Artificial organism creation	Drug production, bioengineering	Playing "God", moral boundaries, meaning of life	Dual-use risk (bioweapons development)	Kurtoğlu *et al*., 2024

Xenotransplantation, on the other hand, has been found to have considerable solutions for organ shortages, but there are considerable risks associated with zoonotic disease transmission. Similarly, transgenic organisms have been found to have considerable solutions for food security, but they are associated with considerable risks of ecological imbalance (Carrier, 2022).

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A. rDNA Technology, CRISPR and Genome Editing

- Advantages: Prevention of diseases, implementation of gene therapy
- Challenges: Germline modification, unintended genetic mutations, exacerbation of social inequalities
- Ethical dilemma: Alterations within the germline have irreversible implications for subsequent generations (Chimekwuwo, 2025).

B. Eugenics

Contemporary advancements in biotechnology rekindle apprehensions regarding positive eugenics (enhancement) Potential for discrimination against individuals deemed "genetically undesirable" Subject to substantial critique owing to historical malpractices (Gay, 2025).

C. In Vitro Fertilization (IVF) and Preimplantation Genetic Diagnosis/Testing

Advantages: Resolution of infertility issues, screening for genetic disorders

Ethical dilemmas: Selection and disposal of embryos Commercialization of reproductive processes Utilization of artificial intelligence in embryo selection raises significant transparency issues (Burden, 2024; Tehsin *et al*., 2021).

D. Cloning

Reproductive cloning (Osadolor & Hernandez, 2025; Chadwick, 2018) in humans is Universally regarded as unethical (Prianto *et al*., 2020). Therapeutic cloning often Holds promise for advancements in regenerative medicine. Cloning of animals raises significant animal welfare concerns (Keefer, 2015)

E. Xenotransplantation

The Use of genetically modified animals (e.g., pigs) for organ transplantation is used widely. The ethical dilemma concerning is the animal suffering and commodification or dignity and zoonotic disease transfer from animals to human. CRISPR based immune modulating procedure though minimize the chances of immune rejections (Carrier, 2022).

F. Transgenic Plants and Animals as Synthetic Biology Tools

The Transgenic plants (Ene, 2024) and Transgenic animals (Mekuriaw, & Tagele, 2016) have foreign DNA to improve and enhance food security and improve nutrition thus alleviating malnutrition. The ethical dilemma is ecological imbalance due to release in the natural ecosystem intentionally or unintentional via horizontal gene transfer to wild relatives in plants and reproduction in animals. The other concern is corporate control over food systems and farming through hybrid sterile seeds and technological dependence as synthetic biology (Kurtoğlu *et al*., 2024).

3.4. Basic Ethical Principles for Biotechnology

Basic ethical principles were consistently pointed out as those principles that are the basis for using biotechnology. The basic ethical principles include autonomy, beneficence, non-maleficence, justice, human dignity, and scientific responsibility. Autonomy applies to reproductive biotechnologies where informed consent must be obtained, while beneficence and non-maleficence apply to therapeutic applications like genetic engineering. Justice emerged as a major concern, especially regarding unequal global access to advanced treatments. Human dignity was a dominant theme in debates surrounding cloning and human genetic modification (Warton *et al*., 2023; Garg *et al*., 2026; Bobier & Hurst, 2026; Martedjo & Setiawan, 2026).

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Table 2. Key Bioethical Principles Identified in Literature.

Ethical Principle	Description	Application in Biotechnology	References
Autonomy	Respect for individual decision-making	Informed consent in Genetic testing/IVF, gene therapy	Warton *et al*., 2023
Beneficence	Promoting well-being	Use of CRISPR to cure genetic diseases in germline	Gantsho, 2022
Non-maleficence	Avoidance of harm	Limiting risky germline editing	Sanders, 2015
Justice	Fair distribution of benefits	Equal access to advanced therapies, specially vulnerable group	Bara & Bugnariu, 2025
Human Dignity	Respect for intrinsic human value	Opposition to reproductive cloning	Garg *et al*., 2026
Responsibility	Accountability in research	Ethical oversight in dual-use research	Bobier & Hurst, 2026
Confidentiality and Privacy	Protection of individual genetic and medical information, ensuring data security and controlled access so that not discriminated on this basis	Secure storage and ethical use of genetic data in genetic testing, PGD, genomic databases, and personalized medicine; prevention of genetic discrimination and misuse of data	Martedjo & Setiawan, 2026

These principles serve as a universal ethical framework, although their interpretation varies across cultural and religious contexts.

3.5. Comparative Ethical Analysis of Technologies

Comparison indicated a considerable difference in acceptance and risk levels between various biotechnologies.

Table 3 provides an insight into the high degree of uncertainty posed by CRISPR technology, which may have both long-term and heritable consequences. Both methods are allowed, but their implementation involves ethical issues because of the changes made to the embryo. Reproductive cloning using humans is not allowed considering issues of identity and dignity. Xenotransplantation, despite being unhealthy for people, is allowed under some circumstances (Shah *et al*., 2026; AGRBM, 2026; Garg *et al*., 2026; Wong & Faris, 2024; Halim, 2025).

Table 3. Comparative Ethical Issues Across Biotechnologies.

Issue	CRISPR	IVF/PGD	Reproductive Cloning	Xenotransplantation	Transgenics
Consent	Limited (future generations)	Required (parents)	Not applicable	Patient consent	Not applicable
Risk Level	High (unknown long-term effects)	Moderate	High	High	Moderate
Ethical Acceptance	Controversial	Generally accepted with	Mostly rejected	Conditionally accepted	Debated

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		merital limits	(human cloning)		
Religious Concerns	Germline/Reproductive modification	Third-party donation	Human replication	Use of animal organs	Genetic alteration
Social Impact	Inequality risk	Family structure issues	Identity crisis	Public health concerns	Food ethics debates
References	Shah *et al.*,2026	AGRBM, 2026	Garg *et al.*, 2026	Wong & Faris, 2024	Halim, 2025

The ethical acceptability will depend on the context because certain factors such as the use of the technology for therapeutic purposes or enhancement, its risk level, and social values would play their roles.

3.6. Assessment of Biosafety and Biosecurity Risks

Several categories of risks associated with advanced biotechnology were introduced in the reviewed literature, namely, laboratory risks, environmental risks, and public health risks.

As shown in Table 4, the laboratory risks include the possibility of accidental exposure to the genetically modified organisms, while the environmental risks relate to unforeseen changes in the environment caused by gene transfer to wild species. In xenotransplantation, there are obvious public health risks, when the cross-species infection may occur (Lerner *et al.*, 2026; Philips *et al.*, 2022; NASEM, 2025; Fishman, 2018; Warmbrod, 2023; Kuzma, 2021).

Table 4. Biosafety and Biosecurity Risk Categories.

Risk Category	Description	Examples	References
Environmental release of GMOs	Unintentional or deliberate release of genetically modified organisms into natural ecosystems/environment, ecological balance concerns	Escape of engineered microbes used in bioremediation into soil or water systems	Lerner *et al.*, 2026
Horizontal gene transfer	Transfer of genetic material between organisms, potentially spreading engineered traits	Antibiotic resistance genes transferring from GM bacteria to native microbes or wild weeds	Philips *et al.*, 2022
Laboratory Risks	Accidental exposure or release	CRISPR lab contamination	NASEM, 2025
Public Health Risks	Disease transmission	Xenotransplantation infections	Fishman, 2018
Dual-use Risks	Misuse for harmful purposes	Synthetic pathogens	Warmbrod, 2023
Regulatory Gaps	Lack of oversight	Unregulated gene editing experiments	Kuzma, 2021

Importantly, dual-use risks were consistently highlighted, especially in synthetic biology and genome editing, where technologies intended for beneficial purposes could potentially be misused

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for harmful applications, including biological weapons development. Regulatory gaps further exacerbate these risks, particularly in regions lacking robust governance frameworks.

3.7. Islamic Bioethical Perspectives

An important dimension of this review is the integration of Islamic bioethics into the evaluation of modern biotechnologies. The findings indicate that Islamic perspectives provide a structured ethical framework rooted in the objectives of Quran, Hadith/sunna and Consensus/Fiqh/Ijmah/Shariah (maqasid al-shariah) and Personal reasoning/qias/intuition or prediction from analogy when without guidance at all (which is very rare), particularly the preservation of life, lineage, human dignity, Morality (Akhlaq), Maslaha (community benefit/damage reduction), Real Necessity/compulsion/dzarura (Isa, 2019), respect (Adab), No harm/spiritual/social/or future (La zarar wa la dzirar) as a regulated use of technology in texual (lafzi), contextual (siyaq-o-sabaq) and para-texual (reasoning as a whole) approach is in accordance with modern ethics philosophy (Fatima *et al*., 2024; Isa, 2019; Ullah, 2026).

"Whoever kills a person unless for a person or for (without) corruption in the land, it is as if he had killed mankind entirely. And whoever saves one life, it is as if he had saved lives of mankind entirely." Surah Al-ma'idah ayat 32 (5:32 Al-Quran)

"O Believers, do not enter other houses than your own until you have the approval of the inmates and have wished them peace (greetings); this is the best way for you: it is expected that you will observe (remember) it." (Surah An-Nur 24: Ayat 27, Al-Quran)

"As for he who is driven by hunger, without being willfully inclined to sin, surely Allah is All-Forgiving, All-Compassionate. (If done prohibited under compulsion, still answerable)" (Surah Al-Ma'idah 5: Ayat 3, Al-Quran)

"He has explained to you what is forbidden to you, except under compulsion (Constrained) of necessity." (Surah al-An'am Ayat 119 (6:119 Al-Quran)

"And do not make mischief in the earth (fasad fil Ardz) after it has been set in order"
(Surah Al-A'raf 7: Ayat 56)

Islamic Bioethics relies on the sources of Islam, which are the Quran and Hadith (Sunnah), and methodologies of Ijma (scholars' consensus), Fiqh (jurisprudence interpretation), and Qiyas (analogical reasoning), all employed within the broad objectives of Shariah (maqasid al-shariah). The objectives emphasize the significance of sustaining life (hifz al-nafs), procreation (hifz al-nasl), intellect, dignity (hifz al-aridz), and societal welfare (maslaha, المصلحة العامة), thus forming an ethical approach ensuring the appropriate application of technological and scientific progress. In cases where there are no explicit guidelines, which is uncommon, analogical and forward-looking analysis (ijtihad) is applied to ensure consistency with the fundamental ethics.

In terms of science and bioethics, this approach is highly consistent with universal bioethical norms, namely beneficence, non-maleficence, justice, and respect for persons. The Qur'anic doctrine of protecting life and human welfare, which is clearly stated in Surah Al-Ma'idah (5:32), states that saving someone's life is like saving the entire world and justifies the use of gene therapy, xenotransplantation, and regenerative medicines to save people's lives if the level of associated risk is minimal and will cause no additional harm. Privacy and the need to obtain consent from participants in the process, emphasized in Surah An-Nur (24:27), are also an essential part of genetic tests in modern science.

The principle of necessity (ḍarūrah), described in Surah Al-Ma'idah (5:3), provides much-needed ethical flexibility, as it makes possible any forbidden act, provided that a person cannot escape from a dangerous situation, and is responsible for their actions. This idea is especially relevant when discussing xenotransplants and using GMOs to remediate environments if such procedures can save human lives and help avoid global catastrophes. Also, Islamic ethics is concerned about the concepts of akhlāq (moral conduct) and adab (proper behavior).

The interpretive approach in Islamic bioethics involves three distinct levels. The first one includes textual (lafẓī) analysis, which implies the examination of evidence in the scripture directly.

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The second level relates to the contextual (siyāq-o-sabāq) reading of the text that considers the context in which the passage occurs and its larger meaning. The third aspect of interpretation is the para-textual reasoning, which combines holistic comprehension with ethical reasoning. In view of the above, interpretative bioethics allows Muslims to address emerging biotechnologies, including CRISPR, cloning, and reproductive methods. As a result, it does not oppose scientific progress itself but supports regulated, morally-based use of innovations in order to promote innovation while preventing damage and benefiting humanity.

According to Table 5, CRISPR editing may be applied therapeutically if the intention is to cure an individual and prevent harm. IVF treatment is considered allowable as long as it remains within marriage, while cloning humans is prohibited because it affects lineage and identity. As regards xenotransplantation, it may be performed on the basis of necessity (darurah) when necessary for saving life (Fatima *et al*., 2024; Isa, 2019; Ullah, 2026; Nurudeen & Lateef, 2026; Rohwiyono *et al*., 2025; Wong & Faris, 2024; Halim, 2025).

Table 5. Islamic Bioethical Perspective on Emerging Biotechnologies.

Technology	Islamic Ruling (General)	Conditions/Justification	References
CRISPR (Therapeutic)	Permissible	If used for treatment and no harm	Fatima *et al*., 2024; Isa, 2019
Germline Editing	Generally discouraged	Affects lineage (nasl)	Ullah, 2026
IVF	Permissible with condition	Within marriage only	Nurudeen & Lateef, 2026
PGD	Permissible with condition	For disease prevention	Nurudeen & Lateef, 2026
Cloning (Therapeutic)	Debated/conditionally allowed	If benefits outweigh harm	Rohwiyono *et al*., 2025
Human Reproductive Cloning and nonmedical-eugenics	Prohibited	Violates human dignity and lineage, Playing God	Rohwiyono *et al*., 2025
Xenotransplantation	Pig Permitted treatments if halal alternative is not available	If life-saving (darurah)	Wong & Faris, 2024
Transgenic Crops	Permissible if Halal permitted source	If safe and beneficial	Halim, 2025
Transgenic animals And synthetic biology	Conditionally permissible	For healthy halal food under maslaha and animal welfare	Halim, 2025

These findings demonstrate that Islamic bioethics is not inherently restrictive, but rather conditional, balancing innovation with moral responsibility.

3.8. Recurring Themes of Ethics in Literature

Through the examination of the thematic synthesis of the previously reviewed scholarly articles, it becomes evident that several ethical dilemmas recur that transcend any singular technological context. The most salient ethical concerns encompassed the challenge of negotiating the equilibrium between risks and benefits, closely succeeded by considerations of dignity, justice, biosecurity, and the emergence of ethical quandaries pertaining to eugenics in relation to advancements in gene

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editing and genetic enhancements (Afshari *et al*., 2025; Cherkassky, 2023; Donohue, 2023; Resnik, 2024; Aarons, 2017; Torrorey-Sawe, 2025).

Table 6. Recurring Themes Identified in Literature.

Theme	Frequency (Qualitative)	Implication	References
Risk vs Benefit	Very High	Central ethical dilemma ethical committees should evaluate	Aarons, 2017
Human Dignity	High	Core concern in Reproductive cloning and editing	Afshari *et al*., 2025
Justice & Equity	High	Access to technologies specially vulnerable and marginalized group	Torrorey-Sawe, 2025
Consent	Moderate–High	Critical in reproductive technologies	Cherkassky, 2023
New Eugenics Concerns	High	Re-emerging ethical issue	Donohue, 2023
Biosecurity	High	Increasing global concern as after Covid19	Resnik, 2024

The issue of consent, particularly regarding embryos and future generations who are unable to provide informed consent, emerges as a significant ethical consideration**.**

3.9. Omics and Systems Biology Applications

The integration of omics disciplines, including transcriptomics, proteomics, and metabolomics, has yielded valuable insights into the regulatory pathways such as the biosynthesis of artemisinin (Shi *et al*., 2024) in *A. annua* (**Figure 5)**. Utilizing gene editing technologies, such as CRISPR/Cas9, metabolic engineering may be employed to optimize the production of specialized metabolites in medicinal flora. Multi-omics integration is a powerful tool for boosting our understanding of interactions of genes, proteins, metabolites to identify new specialized metabolites (Shi *et al*., 2024; Wang *et al*., 2024).

4. Discussion

4.1. Balancing Innovation and Risk of Modern Biotechnology Innovative Techniques

Modern biotechnology embodies a paradox; it possesses the capability to eliminate diseases, yet it may fundamentally transform human identity and societal frameworks. The ethical dilemma is not centered on the feasibility of employing these technologies, but rather on the moral imperative of whether we ought to engage in their application.

The notable biotechnological innovations of the 21st century confer substantial opportunities for enhancing human health and well-being; however, they concurrently introduce considerable ethical and biosafety concerns. An integrative strategy that harmonizes scientific advancement with ethical contemplation and regulatory governance is imperative. Through the promotion of interdisciplinary discourse and the inclusion of varied societal viewpoints, it is feasible to capitalize on the advantages of biotechnology while mitigating its associated risks. The trajectory of biotechnology will be determined not solely by our capabilities, but also by the decisions we make, informed by a dedication to human dignity, social equity, and global accountability.

As can be seen from the technologies in Table 1, there is a dual nature involved since the technologies have revolutionary scientific potential and at the same time create many ethical, social and safety dilemmas. Usually, the severity of ethical concerns increases proportionally to the level of

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intervention within biological processes, especially where hereditable genetic alteration or modification of human identity is considered. As a result, proper use of biotechnology implies combining the process of scientific progress with an ethical framework, as well as regulation and public involvement (Chimekwuwo, 2025; Gay, 2025; Derdour, 2024; Burden, 2024; Kurtoğlu *et al*., 2024; Ene, 2024).

4.2. Comparative Ethical Issues

From the comparative table presented in Table 3 below, one can conclude that ethical considerations in relation to these technologies are directly linked with their scientific aspects. Technologies that imply hereditable genetic manipulation, like CRISPR and cloning, are associated with the highest amount of ethical and sociological controversy because of their consequences. Meanwhile, more conventional technologies, such as IVF and transgenics, are somewhat better integrated in society despite ethical controversies. Xenotransplantation is unique in that it presents a delicate balance of both need and risk of biological danger. Ethical standards based on scientific understanding as well as adaptive regulatory measures are crucial in order to guarantee that technology is employed and developed in a safe and ethical manner. In general, there is more ethical controversy surrounding technologies dealing with inheritable genetic modification and altering identity, such as CRISPR technology and cloning, than other more accepted forms of genetic manipulation such as in vitro fertilization and transgenics. From the comparative analysis, one can see that ethical acceptability hinges upon scientific risks, consent, and sociological implications (Shah *et al*., 2026; AGRBM, 2026; Garg *et al*., 2026; Wong & Faris, 2024; Halim, 2025).

4.3. Biosafety, Biosecurity and Dual-Use Concerns

Biotechnologies like CRISPR are dual use technologies which can either be used to cure diseases or cause biological warfare. The use of synthetic biology in developing a vaccine or a pathogen exemplifies this issue. It requires global regulation, ethical training, and regulatory harmonization.

The various risks posed by biotechnology (see Table 4) can be summarized as environmental, genetic, laboratory, public health, and geopolitical. The environmental and evolutionary risks associated with the release of GMOs and horizontal gene transfer reflect the ecological consequences of genetic modifications while the laboratory and public health risks stress the importance of containment as well as disease-prevention measures. The dual-use nature of biotechnology calls for the adoption of ethics while the regulatory gap points at existing weaknesses of regulatory bodies in dealing with biotechnology. These risks clearly indicate that while biotechnology offers tremendous opportunities, they need to be complemented with appropriate scientific protection mechanisms, constant monitoring, and regulatory measures (Lerner *et al*., 2026; Philips *et al*., 2022; NASEM, 2025; Fishman, 2018; Warmbrod, 2023; Kuzma, 2021).

4.4. Islamic Stance Towards Modern Biotechnology

The Islamic ethical framework regarding biotechnology (Table 5) considers a balanced and conditional stance regarding new developments in biotechnology, taking into consideration both scientific evidence as well as moral and legal factors. While the application of technologies like CRISPR and PGD is permissible as they contribute to maintaining health and preventing harm, germline modification and cloning for reproductive purposes are prohibited owing to lineage considerations, questions concerning human dignity, and uncertainty about their long-term consequences. On the other hand, assisted reproduction through IVF is permitted only in the context of marital relationships, while xenotransplantation is considered permissible when necessitated. In general, transgenic technology is assessed based on its safety, utility, and adherence to halal requirements (Fatima *et al*., 2024; Isa, 2019; Ullah, 2026; Nurudeen & Lateef, 2026; Rohwiyono *et al*., 2025; Wong & Faris, 2024; Halim, 2025).

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4.5. The Recurring Themes in Literature

The common themes identified within the body of literature show that the ethical issues related to biotechnology are intertwined and grow together with advancements within science. The ongoing conflict between risk and benefits, the respect for human dignity, the call for justice and fairness, the intricacies of obtaining consent, the comeback of eugenics, and the importance of biosecurity form the basis for the ethics of contemporary biotechnology. The latter has been growing increasingly important since the COVID-19 pandemic period when the world witnessed how impactful biological threats can be. All of these issues indicate that scientists' work should be regulated not only scientifically but also ethically, with an emphasis on the development of adaptive regulatory systems, which is not possible without unified international regulation policies, cultural differences, and fast technological advancements (Aarons, 2017; Afshari *et al*., 2025; Torrorey-Sawe, 2025; Cherkassky, 2023; Donohue, 2023; Resnik, 2024).

Future Prospects

Future efforts in advanced biotechnology should prioritize the development of robust global governance frameworks that harmonize regulations across countries while addressing dual-use and biosecurity risks. There is a critical need to integrate ethical literacy and interdisciplinary education into scientific training, ensuring that researchers are equipped to evaluate the societal implications of their work. Long-term safety studies, particularly for genome editing and xenotransplantation, must be strengthened to assess unintended consequences across generations. Policymakers should promote equitable access to emerging technologies to prevent genetic inequality and modern forms of eugenics. Additionally, public engagement and transparent dialogue are essential to build trust and inclusivity in decision-making processes. Incorporating religious and cultural perspectives, including Islamic bioethics, can further enhance context-sensitive ethical frameworks. Ultimately, a balanced approach combining innovation, ethical responsibility, biosafety, and global collaboration is essential to ensure that biotechnology advances in a safe, just, and sustainable manner.

Conclusion

Advanced biotechnology stands at the frontier of human progress, offering transformative solutions to global health, Agriculture, Industrial and environmental challenges. However, it simultaneously raises complex ethical, social, and existential questions. Ethical concerns are not new, but intensified by technological power. CRISPR and related tools demand strict oversight and global consensus. Religious perspectives, including Islam, provide valuable ethical guidance. A multidisciplinary approach is essential to ensure responsible innovation.

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