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Original Article

An analysis of the Dimensions and Risk Management Strategies for the Biotechnology

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Abstract

Introduction: Despite the expansion and development of the field of biotechnology, concerns persist regarding the risks and dangers associated with this sector. The aim of the current research was to prioritize and manage the risks in Iran's biotechnology sector.

Materials and Methods: The Meta Synthesis Model (qualitative), Kappa coefficient calculation, and Delphi technique (quantitative) were utilized in this study to identify biotechnological risks. The research encompassed all articles published in English from 2012 to 2022. The Delphi technique engaged experts in biotechnology who were well-versed in risk management. To determine the study population, all researchers in relevant subject areas were identified, and four were selected through purposive sampling.

Results: Based on published sources, 56 risks were identified in the field of biotechnology. Using the Shannon entropy method and evaluating the frequency of these risks, 34 were classified as high-priority. The findings indicated that the most significant challenge in biotechnology pertains to the risks associated with human exposure to products contaminated by toxins and biotechnological pollution, which could potentially enter the human body. Therefore, human health emerged as the most critical risk. Furthermore, the results from the fuzzy Delphi technique emphasized that the highest-scoring biotechnological risk in Iran involved human exposure to products affected by toxins and biotechnological pollution.

Conclusions: Through pairwise comparison of criteria by experts, it was revealed that challenges related to water and marine resources are among the most important biotechnological risks, with health and medical issues closely following.

Keywords: Risk Management, Biotechnology, Biotechnology Risk, Iran

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Introduction

In 2012, researchers discovered a new technology in advanced gene editing, which surprised the scientific community. This technology enabled the editing of DNA in all living organisms, providing new possibilities for research and development. These innovations in biotechnology have created new possibilities and led to the emergence of uncertain risks.[1] Given that the field of biotechnology has not yet acquired complete knowledge on these issues and they are known as "known unknowns," it is crucial to identify the dangers and risks facing this field.[2] Challenges in this field range from technical issues such as off-target mutations[3] to social concerns arising from biotechnological advances, including the production of biological weapons,[4] legal issues, and religious issues.[4,5] While most concerns and challenges revolve around the applications of biotechnology, such as in agriculture and the environment, this also underscores the importance of uncertain risk management in other fields and industrial biotechnology.[1] From the perspective of the European Risk Management Organization, risk management includes guidelines for preventive actions when dealing with significant challenges such as social, environmental, and medical threats.[6] According to existing laws regarding biotechnology, despite the field's expansion and development, there are still concerns about the risks and dangers it faces, largely because the risks are completely unknown.[7] Considering the rapid advances and increasing unknown challenges in biotechnology, focusing excessively on measurable risks may demotivate researchers from discovering and learning about these risks, potentially leading to significant knowledge gaps in biotechnology risk management.[8] Therefore, the biotechnology sector needs to accurately identify the risks and challenges it faces to effectively plan against unforeseen risks.

Effective risk management should include a flexible assessment method, taking into account the complexity, uncertainty, or ambiguity of risks.[9] To discover the level of complexity and degree of difficulty of the challenges facing the field of biotechnology, it is necessary to understand the risks and challenges precisely and thoroughly. It is clear that making changes in any organization and developing innovation

entails many challenges and risks, and the field of biotechnology is no exception. The International Standard Organization defines "risk" as a combination of the probability of an event and its effects.[10] Therefore, determining all the possible risks in a process and their probability of occurrence is a key part of risk assessment in the biotechnology field. Recognizing risk and being aware of its consequences, functions, and effects helps develop risk management in biotechnology. Biotechnology managers and activists cannot properly manage risk until they fully understand it. These risks and challenges have several consequences for biotechnology, all caused by our misunderstanding of risk and the dangers that arise from it. Based on this, risk management can be defined as a continuous and organized process in biotechnology to determine, evaluate, and decide on the response to and reporting of opportunities and risks that affect the achievement of goals.[1] The risk management process includes risk recognition, risk assessment, and risk control. The first step in this process is to identify the risks and dangers faced by organizations so that, after identification, a plan to manage them can be developed.[11]

Various studies have focused on identifying and managing risks in biotechnology, but comprehensive research covering all aspects of risk in this field has not yet been conducted. For instance,[1] emphasized the importance of understanding and accurately evaluating risks to mitigate potential damages, identifying human health as the primary concern related to biotechnology products. Yoo and Chavas[12] explored the role of risk aversion in adopting genetically modified corn in the U.S., finding that ethical concerns make farmers more hesitant to accept this technology. Guida[13] assessed technological risks and uncertainties in international biotechnology trade, highlighting the inadequacy of current risk assessments for informed decision-making by the World Trade Organization (WTO) and suggesting improvements to increase the reliability of biotechnology legal decisions. Additionally, Strain[14] analyzed European policies and laws regarding biotechnological risks, identifying regulatory tensions and challenges affecting the future of biotechnology. Bouchaut and Asveld[1] reviewed advanced gene editing techniques, pinpointing expectations, applications, and transparency as major risk areas. Sax and Doran[6] studied responses to biotechnological risks, noting that individuals with higher uncertainty aversion reacted more negatively to ambiguous risks. Colombaroli-Carneiro et al.[15] found that market and human resource risks were the highest in biotechnology development, while financial, product requirement, and production risks were lower. Fernald et al.[16] discussed the trade-offs in strategic alliances for biotechnology commercialization, suggesting that increased participation in product development alliances reduces risks and enhances cooperation.

As it is clear from the above, no comprehensive research has been done in the field of biotechnology risk management. Therefore, the purpose of the current research is to manage the risks in the field of biotechnology in Iran. The current research can lead to the development of concepts and theoretical knowledge in risk identification, risk management, and recognition of favorable and unfavorable risks facing biotechnology. This will provide a comprehensive solution and roadmap for risk management in the area of biotechnology and open up possibilities for additional research on risk management. Therefore, to achieve the goals of the research, the following questions were asked: a) What risks have been identified in the biotechnology area in the world so far? and b) What is the prioritization of the risks facing biotechnology from the point of view of Iranian experts?

Materials and Methods

In this mixed methods research, a combination of qualitative and Delphi (quantitative) techniques was employed. The scope of the research included all scientific articles published between 2012 and 2022 in Persian and English languages. Therefore, all articles published during the ten-year period and indexed in different databases were examined. In the current research, five English databases including Google Scholar, Science Direct, Springer, Scopus, and Web of Science, as well as five Persian databases including Normagz, Magiran, Civilica, Humanities Database, and Tehran University Journals Database, were searched with specific keywords (Table 1). This approach helped identify sources published in these areas.

Table 1. Keywords Searched in Databases

Keywords searched in the database
Risks facing the field of biotechnology
biotechnology+Risks
Biotechnology risk
Challenges facing biotechnology
AND biotechnology Risks
Biotechnology* Risk
Biotechnology challenge
Challenges of biotechnology development

In the Delphi technique, the research community included all biotechnology and risk management specialists. To determine the exact number of people in the society, all researchers who have conducted research in the subject areas presented in the Table 1 were identified. Then, 24 individuals were selected through purposive sampling. The Meta Synthesis Model was employed to identify the risks facing the field of biotechnology, and the Delphi technique was used to rank and prioritize the identified risks.

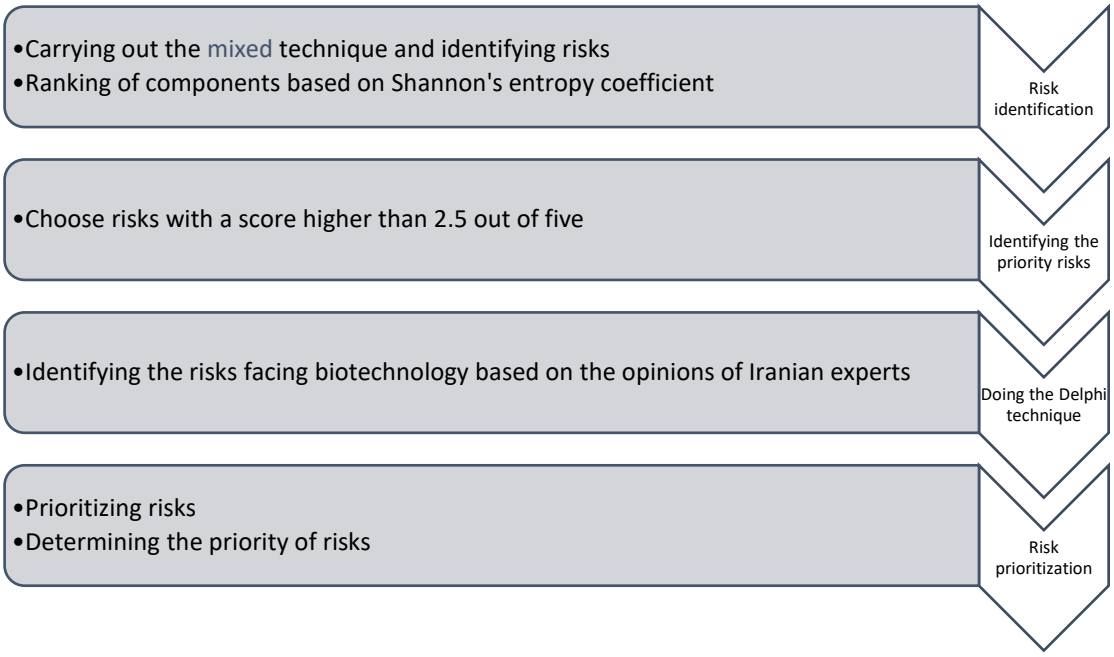

Figure 1. Implementation Process of the Research

Results

The aim of the current research was to analyze risk management in Iran's biotechnology field. 56 risks in biotechnology were identified after reviewing the literature and conducting a meta-analysis. 34 high-priority risks were determined using the Shannon entropy method and by analyzing the frequency of risks in scientific sources. The identified risks were ranked based on their occurrence frequency in the reviewed articles and sources. These items are presented in Table 2.

As shown in Table 2, the most important biotechnological risk is related to the risks of human use of products affected by biotechnological materials and the possibility of these materials entering the human body. Therefore, the most important challenge and risk is related to human health. Other risks that require special attention are concerns about air pollution due to the use of biotechnological pesticides in agriculture, concerns about soil pollution due to the use of biotechnological pesticides in agriculture, endangerment of animal welfare, and ethical issues in the use of biotech nological products. There is concern about water pollution due to the use of biotechnological pesticides and toxins in agriculture, and concern about damaging underground water sources.

The second research question is: How is the prioritization of biotechnological risks viewed by Iranian experts? The Delphi technique was used to measure the importance of the proposed components in the field of biotechnology and rank them accordingly. In this study, the extracted criteria and components were provided to 25 experts, who were asked to rate each of the extracted risks on a scale of 1 to 5 in terms of importance and attention. Finally, 24 of these experts reviewed the criteria and sent their feedback to the researcher. The average ratings from these experts, on a scale of five points, are presented in Table 3.

As shown in Table 3, the most important challenge facing the field of biotechnology, which has received the highest score from Iranian experts, is related to the risks of human use of products affected by toxins and biotechnological pollution, and the possibility of these toxins and pollution entering the human body. Challenges such as risks related to biotechnological product residues for the earth, unknown risks in the use of transgenic agricultural products, risks related to the loss of biodiversity, ethical issues in the use of biotechnological products, concern about water pollution due to the use of biotechnological toxins in agriculture, and concern about damaging underground water resources were also identified as the most important risks facing Iran's biotechnology field.

Among the identified risks, some are more specific to Iran due to its unique environmental, social, and economic conditions. These include concerns about groundwater contamination, soil degradation, and the high costs of producing biotechnological materials, which are particularly challenging in the context of Iran's agricultural practices and resource management. Additionally, issues such as limited public awareness and the presence of both accurate and misleading information regarding biotechnological products resonate strongly within the Iranian context, emphasizing the need for localized education and regulation.

Table 2. Challenges Facing Biotechnology in the World

Row	Risk	Dimension	Rank
1.	People's concerns about the risks of using biotechnological materials for their health are high.	Health and medicine	5
2.	Biotechnological risks causing physical harm to humans.		3
3.	Effects and brain damage of using biotechnological products		5
4.	Harms of using poisons to humans and animals.		7
5.	Concerns about the sterilization of people due to the high use of biotechnological products		6
6.	Problems related to the presence of silent infections in biotechnological drugs		5
7.	The risks of human use of products affected by toxins and biotechnological pollution, and there is a possibility of these toxins and pollution entering the human body.		1
8.	Concerns about an increase in brain tumors and psychological problems with the use of biotechnological products	Technology issues	5
9.	Consumers do not have the necessary expertise to distinguish between correct and incorrect information on biotechnology materials.		6
10.	There is a lot of true and false information about the use of biotechnological products and it is difficult for consumers to distinguish this type of information.		6
11.	Laboratory biohazards of biotechnological products	Environment and agriculture	4
12.	Risks of biotechnological product residues for the earth		6
13.	Risks related to toxins released by biotechnological crops on farms.		4
14.	Concerns about air pollution due to the use of biotechnological pesticides in agriculture		2
15.	Concerns about soil contamination due to the use of biotechnological pesticides in agriculture		2
16.	Unknown risks in the use of genetically modified agricultural products		4
17.	The dangers of using pesticides and chemical additives		5
18.	The multidimensional dangers that poison bring to agricultural products.		5
19.	Risks of biodiversity loss		3
20.	The dangers of reducing land fertility		3
21.	Risks of destroying beneficial insects due to spraying of biotechnological products		5
22.	Risks of damaging healthy products		3
23.	The risks of transferring weed resistant genes and the increase of these weeds		4
24.	Endangering the comfort of animals		2
25.	Dangers related to the excessive use of toxins that lead to serious harm to humans, soil and animals.		3
26.	Elimination of indigenous and genetic products		3
27.	Violation of human rights in the use of biotechnology products	Legal and ethical issues	2
28.	Ethical issues in the use of biotechnological products		2
29.	The complexity of producing biotechnology products is very high.	Industrial issues	6
30.	There is no proper understanding of market needs in the field of biotechnology.		6
31.	High costs of producing biotechnological materials		5
32.	Concerns about water pollution due to the use of biotechnological pesticides in agriculture	Water and marine resources	2
33.	Concerns about damaging groundwater resources		2
34.	Risks of genetic modification of aquatic animals due to the use of various toxins for the preservation of biotechnological products		3

Table 3. Risk Ranking Results Obtained from the Delphi Technique

Risk classification	Row	Dimensions	Score	Rank
Health and medicine	1.	The dangers of human use of products that have been affected by biotechnological toxins and pollution and there is a possibility of these toxins and pollution entering the human body.	4.45	1
Water and marine resources	2.	Concerns about damaging groundwater resources	4.4	2
Health and medicine	3.	The problems of silent infections in biotechnological drugs	4.3	3
Environment and agriculture	4.	Risks of biotechnological product residues for the earth	4.3	3
Environment and agriculture	5.	Unknown risks in the use of genetically modified agricultural products	4.3	3
Environment and agriculture	6.	Risks of biodiversity loss	4.3	3
Legal issues	7.	Ethical issues in the use of biotechnological products	4.3	3
Water and marine resources	8.	Concerns about water pollution due to the use of biotechnological pesticides in agriculture	4.3	3
Health and medicine	9.	Harms related to the use of poisons to humans and animals	4.2	4
Environment and agriculture	10.	Risks of destroying beneficial insects due to the spraying of biotechnological products	4.2	4
Environment and agriculture	11.	The dangers of excessive use of poisons that lead to serious harm to humans, soil and animals.	4.2	4
Industrial issues	12.	High costs of producing biotechnological materials	4.2	4
Environment and agriculture	13.	The risks of toxins released by biotechnological products in farms.	4.15	5
Environment and agriculture	14.	Concerns about soil contamination due to the use of biotechnological pesticides in agriculture	4.15	5
Environment and agriculture	15.	The multidimensional dangers of pesticides to agricultural products.	4.15	5
Environment and agriculture	16.	Risks related to the use of pesticides and chemical additives	4	6
Environment and agriculture	17.	Concerns about air pollution due to the use of biotechnological pesticides in agriculture	4	6
Technology issues	18.	Consumers do not have the necessary expertise to distinguish between correct and incorrect information on biotechnology materials.	4	6

Health and medicine	19.	People's concerns about the risks of using biotechnological materials for their health are high.	4	6
Environment and agriculture	20.	Elimination of indigenous and genetic products	3.9	7
Water and marine resources	21.	Risks of genetic modification of aquatic animals due to the use of various toxins for the preservation of biotechnological products	3.9	7
Health and medicine	22.	Biotechnological hazards that cause physical harm to humans.	3.8	8
Environment and agriculture	23.	The risks of transferring weed resistant genes and the increase of these weeds	3.8	8
Industrial issues	24.	There is no proper understanding of market needs in the field of biotechnology.	3.8	8
Health and medicine	25.	Effects and brain damage related to the use of biotechnological products	3.7	9
Environment and agriculture	26.	The dangers of reducing land fertility	3.7	9
Technology issues	27.	There is a lot of true and false information about the use of biotechnological products and it is difficult for consumers to distinguish this type of information.	3.6	10
Environment and agriculture	28.	Risks related to damaging healthy products	3.6	10
Environment and agriculture	29.	Endangering the comfort of animals	3.4	11
Legal issues	30.	Violation of human rights in the use of biotechnology products	3.3	12
Environment and agriculture	31.	Laboratory biohazards of biotechnological products	3	13
Health and medicine	32.	Concerns about an increase in brain tumors and psychological problems with the use of biotechnological products	3	13
Industrial issues	33.	The complexity of producing biotechnology products is very high.	2.9	14
Health and medicine	34.	Concerns about the sterilization of people due to the high use of biotechnological products	2.5	15

According to the average of the challenges mentioned in the table above, all of them are greater than 2.5. Therefore, the results of the current research indicate that the degree of challenges facing biotechnology is higher than average in all the cases mentioned.

In the present study, hierarchical analysis and prioriti zation of risk categories were also performed. In the first stage, 6 main categories of research were prepared in the form of a questionnaire and given to 8 experts, who were asked to do pairwise comparisons of the components. They were graded based on a range of 1 to 6, from equally important to completely more important. In the next step, all criteria were coded and defined, and the results are presented in Table 4.

Table 4. Determination of Criteria and their Definition

Category	Code	Definition
Health and medicine	A	It is related to human health and medical issues and can endanger human health. Issues such as the effect of biotechnological products on the human brain, the general health of people, the mental health of people, etc.
Technology issues	B	It is related to issues caused by the effects of technology and biological artificial intelligence.
Environment and agriculture	C	Issues have arisen with the expansion of biotechnology in the field of agriculture and environment and have created challenges for biotechnology.
Legal issues	D	The issues are related to legal concerns, human rights, ethical issues and religious issues that have been created by the development of biotechnologies.
Industrial issues	E	Issues and problems caused by industrial and modern issues, including the creation of biological weapons of mass destruction, etc.
Water and marine resources	F	Issues caused by the use of toxins, pesticides and biotechnological products pollution to marine and water resources.

Table 5. Fuzzy Pairwise Comparison based on Experts' Opinion

	A			B			C			D			E			F		
A	1	1	1	0.25	0.33	0.5	0.16	0.2	0.25	0.33	0.5	1	1	1	1	2	3	4
B	2	3	4	1	1	1	1	2	3	0.33	0.5	1	4	5	6	0.35	0.33	0.5
C	4	5	6	0.33	0.5	1	1	1	1	2	3	4	4	5	6	0.33	0.5	1
D	1	2	3	1	2	3	0.25	0.33	0.5	1	1	1	4	5	6	0.69	1	1.71
E	1	1	1	0.16	0.30	0.35	0.16	0.3	0.35	0.16	0.3	0.35	1	1	1	0.160	.3	0.35
F	0.25	0.33	0.5	2	3	4	1	2	3	0.58	1	1.44	4	5	6	1	1	1

After defining the criteria, a list was prepared in the form of an Excel file and sent to the experts. They were asked to compare each criterion with the other criteria and put the number one in front of the answer. Finally, all the data were merged, and the pairwise comparison matrix of criteria was created. The results are presented in Table 5.

Table 6. Fuzzy Addition of Lines and Fuzzy Composite Expansion of Criteria

	Fuzzy sum of each row			Fuzzy compound expansion		
A	7.95	10.75	14.45	0.04	0.07	0.13
B	12.91	18.33	24.5	0.06	0.12	0.22
C	16	21.50	28	0.08	0.14	0.25
D	13.25	18.43	24.27	0.06	0.13	0.21
E	5.99	6.74	8.02	0.03	0.04	0.07
F	19.83	26.33	32.94	0.1	0.17	0.29

Table 7. Measuring the Degree of Preference of the Components

	The degree of preference of Si over Sk									The degree of preference	Preference normalization
C	1	1	1	1	0.82	1	1	1	1	0.82	0.22
E	0.54	0.07	0	0.05	0	0.54	0.06	0.88	0.35	0	0.02
B	1	0.86	0.99	1	0.69	1	1	1	1	0.69	0.19
A	0.56	0.4	0.55	1	0.21	1	0.39	1	0.79	0.21	0.14
D	1	1	0.87	1	0.69	1	1	1	1	0.69	0.17
F	1	1	1	1	1	1	1	1	1	1	0.26

In the following, the method of Fuzzy Number Addition and fuzzy compound expansion was employed to calculate the relative weight of the criteria and determine the contribution of each of them in choosing the most important risk. The results of this section are presented in Table 6.

In the next step, the degree of preference for each component was calculated and the final graph of the degree of preference was drawn after normalization.

As shown in Figure 2, the criteria of challenges in the field of water and marine resources are among the most important risks facing biotechnology according to experts, followed by health and medical issues.

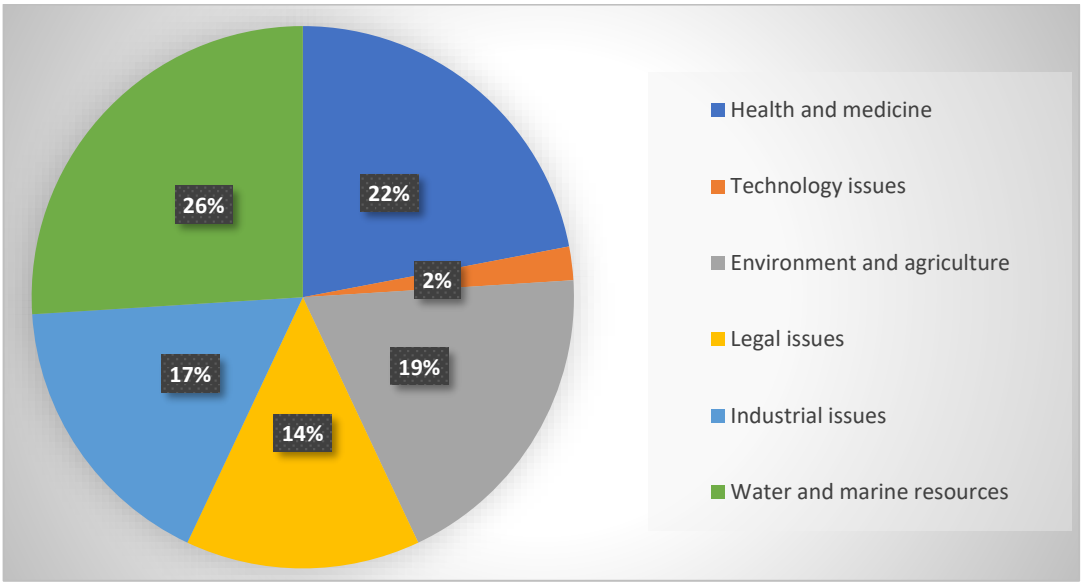

Figure 2. Prioritizing the Risks Facing Iran's Biotechnology (research findings).

Discussion

The findings of this research highlight a wide array of risks associated with biotechnology in Iran, underscoring the complex interplay between environmental, health, economic, and ethical dimensions. These risks are deeply influenced by the country's unique socio-economic conditions and environmental challenges, making it imperative to adopt a localized and multidisciplinary approach for risk management.

One of the critical insights from this study is the dominance of human health risks caused by biotechnological toxins, which can enter the human body through contaminated products. This finding aligns with global studies[1,4,8,17,21] but takes on heightened importance in Iran due to gaps in public awareness, misinformation, and inadequate regulatory frameworks. The inability to effectively differentiate between safe and unsafe biotechnological products leaves consumers vulnerable to health hazards, emphasizing the urgent need for public education and stricter enforcement of safety standards.

Other significant risks include air pollution due to biotechnological poisons in agriculture, as noted in other studies.[22-27] Additional concerns include soil pollution from biotechnological pesticides, threats to animal welfare, ethical issues in using biotechnological products, water pollution from biotechnological pesticides in agriculture, and damage to underground water sources. The fuzzy Delphi technique

highlighted that the most pressing challenge in Iran's biotechnology, according to experts, is the risk from human use of products affected by toxins and biotechnological pollution. The persistence of biotechnological product residues in the environment was also significant. This study's findings are consistent with other studies.[1,28-30] Unknown risks in using transgenic agricultural products, reduced biodiversity, ethical issues, and concerns about water and underground water pollution are also crucial in Iran's biotechnology sector.

The research indicates that biotechnology in Iran faces significant risks and requires special attention to these challenges. The paired comparison of criteria revealed that water and marine resource challenges are the most critical risks, primarily due to toxins and pollutants causing genetic changes in aquatic animals, which can transfer to humans and pose health risks. The use of various poisons and pesticides in agriculture also damages soil and groundwater, leading to further pollution and potential harm to humans and animals. These results align with other findings.[1,6] This study provides a comprehensive analysis of prioritizing risks in biotechnology, useful for stakeholders in the field.

Ethical dilemmas and concerns about transgenic agricultural products further complicate the biotechnology landscape. Reduced biodiversity, displacement of indigenous species, and long-term ecological impacts pose significant ethical and practical challenges. Public skepticism toward genetically modified organisms (GMOs) in Iran is compounded by cultural resistance and insufficient communication of scientific evidence, highlighting the need for transparent and inclusive engagement with various stakeholders. Economic barriers also present a formidable challenge. High production costs and limited alignment between biotechnology innovations and market demands hinder the sector's potential growth. Furthermore, the lack of adequate investment in research and development exacerbates these challenges, limiting Iran's ability to compete globally. Addressing these economic constraints requires a coordinated effort between academia, industry, and government to align biotechnology advancements with national priorities and market needs. The interconnected nature of these risks is a key finding of this research. For example, excessive use of biotechnological pesticides not only harms soil and water but also disrupts ecosystems and human health, demonstrating how risks in one area can cascade into others. This underscores the need for an integrated approach to risk assessment and management that incorporates environmental science, public health, socio-economic analysis, and ethical considerations.

In summary, the discussion highlights the multifaceted challenges facing Iran's biotechnology sector. It emphasizes the importance of localized, comprehensive, and multi-disciplinary strategies to address these risks and unlock the potential of biotechnology for sustainable development.

Conclusion

This study provides a robust framework for understanding and addressing the risks associated with biotechnology in Iran, offering a localized perspective that integrates expert opinions, empirical data, and systematic methodologies. The prioritization of 56 risks, with 34 identified as high priority, underscores the critical areas that require immediate attention. Human health risks, particularly those stemming from biotechnological toxins, are identified as the most pressing challenge. These toxins, which can infiltrate the food chain and accumulate in the human body, pose severe threats to public health. The lack of effective regulatory frameworks and widespread misinformation further compound this issue. To address this, the study recommends the development of stringent safety standards, robust monitoring mechanisms, and widespread public education campaigns to mitigate health-related risks. Environmental risks are equally critical, particularly in the context of Iran's resource limitations. Soil degradation, groundwater contamination, and biodiversity loss caused by the overuse of biotechnological pesticides threaten agricultural sustainability and ecological balance. Addressing these risks requires the adoption of environmentally friendly biotechnological practices, stricter regulations on pesticide use, and investment in innovative solutions to reduce long-term environmental impacts.

Ethical concerns, including the displacement of indigenous species and reduced biodiversity, highlight the importance of developing ethical guidelines and fostering public trust in biotechnological products. Transparent communication strategies and inclusive public engagement are essential to address cultural and societal resistance to GMOs and other biotechnological advancements. Economic challenges, such as high production costs and misalignment with market demands, underscore the need for strategic investment in research and development. Collaboration between industry, academia, and government is crucial to align biotechnology innovations with market needs and national priorities. Creating incentives for private sector investment and fostering public-private partnerships can further support the growth of the biotechnology sector in Iran. This study also highlights the need for an integrated approach to risk management. The interconnected nature of biotechnology risks requires a holistic framework that considers the interactions between environmental, health, economic, and ethical dimensions. Policymakers must adopt a systems-thinking approach to develop comprehensive solutions that address the root causes of risks while promoting sustainable development.

Finally, the following are recommended for further investigation:

- Policy and Regulatory Development: Establishing comprehensive regulatory frameworks to monitor and control the use of biotechnological products, with a focus

on safety, sustainability, and ethical considerations.

- Public Awareness Campaigns: Developing targeted education programs to inform the public about the benefits and risks of biotechnology, reducing misinformation, and building trust in biotechnological advancements.
- Sustainable Practices: Encouraging the use of environ mentally friendly biotechnological methods to minimize soil and water contamination and preserve biodiversity.
- Investment in Research and Development: Allocating resources to advance innovative solutions that address the high costs and complexities of biotechnology production.
- Case Studies and Best Practices: Conducting in-depth case studies to provide actionable insights and operational solutions for managing biotechnology risks in Iran.

By addressing these priorities, Iran can harness the transformative potential of biotechnology while safeguarding human health, environmental integrity, and socio-economic stability. This research serves as a foundational step toward a safer, more sustainable integration of biotechnology into Iran's development framework.

Conflict of Interest Disclosures

The author declares that they have no conflicts of interest.

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