GENETICALLY MODIFIED ORGANISMS

OVERVIEW OF GENETICALLY MODIFIED ORGANISMS (GMO) POLICIES IN INDIA, SUGGESTED REVISIONS AND PROPOSAL OF A RISK CALCULATION SYSTEM FOR GM MICROORGANISMS

prepared by

TEAM iGEM IISc

igem.ug@iisc.ac.in

2025

ACKNOWLEDGEMENTS

We express our sincerest gratitude to everyone who has contributed knowingly and unknowingly to the development of this report.

This text would not have materialized if it were not for the continuous efforts led by Chandana Valaboju and Creetika Dahal, member of our Human Practices and Wet Lab teams, and Team Lead, respectively. We also thank Dr. Lavanya Bhagawatula for encouraging our initiative and providing support.

The ‘Genetically Modified Organisms in India: Regulatory Policies, Comparison with Global Policies and Suggested Revisions’ report published by the IISER Bhopal iGEM team in 2020 has also provided great inspiration and structure to our document. Additionally, we are grateful to the SCP Foundation and their ACS (Anomaly Classification System) for providing a solid framework upon which we built our risk classification system.

ABBREVIATIONS

A

- AMR: Anti-Microbial Resistance

B

- Bt: Bacillus thuringiensis

C

- CBD: Convention on Biological Diversity
- CPB: Cartagena Protocol on Biosafety

D

- DACFW: Department of Agriculture, Cooperation & Farmers Welfare
- DARE: Department of Agricultural Research and Education
- DBT: Department of Biotechnology
- DLC: District Level Committee

F

- FSSAI: Food Safety and Standards Authority of India

G

- GE: Genetically Engineered (or) Genetic Engineering

- GEAC: Genetic Engineering Appraisal Committee
- GM: Genetically Modified
- GMO: Genetically Modified Organism

I

- IBSC: Institutional Biosafety Committee

L

- LMO: Living Modified Organisms

M

- MoEF&CC: Ministry of Environment, Forests & Climate Change

R

- RCGM: Review Committee on Genetic Manipulation
- RDAC: Recombinant DNA Advisory Committee

S

- SBCC: State Biotechnology Coordination Committee

SECTION ONE

OVERVIEW OF GENETICALLY MODIFIED ORGANISMS (GMO) POLICIES IN INDIA AND SUGGESTED REVISIONS

1. INTRODUCTION

With the advent of genetic engineering tools, the goal of creating an organism that could perfectly suit our needs and goals is close to complete realization. The reasons for creating GMOs can be many – better yield of crops, increased quality and disease resistance of foodstuffs like probiotics, supplements, additives etc., attenuating certain harmful behaviors of microorganisms like Anti-Microbial Resistance (AMR), and reducing production costs, to name a few.

While this is an exciting time in the field of biotechnology, it is crucial to be wary of the different consequences and potential detrimental effects that GMOs can bring about. It is important to recognize that the genetic engineering techniques we, as a scientific community, have come up with are not infallible, and hence, act as such.

In this document, we give a brief overview of the existing regulations and guidelines in India, compare them with the counterparts in other countries, and suggest revisions. We also analyze and compare different genetic engineering techniques and introduce a novel risk assessment system that a new researcher could theoretically use to locate exactly what aspects their project covers and calculate the potential risk level for their project.

We hope this document can help future iGEM teams and researchers in general to optimize their experimental protocols to the highest standards of biosafety and biosecurity.

1.1 GENETICALLY MODIFIED ORGANISMS

Genetically Modified Organisms are organisms whose genetic material (either composition or arrangement) has been artificially altered using genetic engineering techniques. It specifically means using molecular biology tools as opposed to conventional methodologies of inducing genetic modifications, such as crossbreeding.

An exact definition for GMOs is difficult to pinpoint, owing to the wide spectrum of opinions and inhibitions towards it. It therefore bodes us well to target misinformation and promote critical thinking to march towards a cohesive universal description, rather than nitpicking existing definitions. This report has deliberately refused to engage in pedantic definition comparisons for this reason.

1.2 APPLICATION OF GMOs

GMOs are applied in different fields, ranging from food, agricultural crops to drug research and diagnosis.

- Creation of higher yield and disease resistant crops, helping to decrease the usage of expensive pesticides and fertilizers, which can have adverse environmental effects as well. Other problems like drought, salinity, and weeds can be tackled with the help of Genetic Engineering.

  In a way, farmers have been doing genetic engineering for as long as civilization itself, in the form of selective breeding and cross-fertilization to impart desirable traits in plants.

- Diagnostic purposes: A benign microorganism can be genetically engineered to produce a signal (fluorescence signal) upon the detection of a certain compound. This is most suitable for in-vitro detection of the said compound.

- Disease remediation: Stem cell derived diseases can be cured at the grassroot level by modifying the gene responsible for the anomaly, hence stopping the propagation and production of more cells with the same defect.

- Drugs and medicines: Presently, 100% of human insulin used globally is produced using GMOs. This was first approved in 1982. Other therapeutics, vaccines, and monoclonal antibodies are also produced using GMOs. Similarly, GMOs can be purposed as ‘bioreactors’ to produce the required drugs.

- Genetic Engineering is not proposed to replace any of the conventional methods, but is meant to be used as a complement to them.

2. GMO POLICY IN INDIA

2.1 ACTS REGARDING GMOs

India regulates GMOs primarily through the **Environmental Protection Act, 1986**. The country does not have a special provision for GMOs specifically, and has sections in relevant acts. Most of the monitoring is done through the **Rules for the manufacture, use/import/export and storage of hazardous microorganisms/genetically engineered organisms or cells, 1989.** These rules were notified by the Ministry of Environment, Forest and Climate Change (MoEF&CC) under the Environment (Protection) Act, 1986.

2.1.1 ENVIRONMENTAL PROTECTION ACT (1986)

The EPA was enacted by the Parliament of India and came into effect in November 1986. It was based on the consensus set by the United Nations Conference on Human Environment. The Central Government is empowered to take the necessary measures and create authorities to deal with environmental issues.

2.1.1.1 RULES FOR THE MANUFACTURE, USE/IMPORT/EXPORT, AND STORAGE OF HAZARDOUS MICROORGANISMS/GENETICALLY ENGINEERED ORGANISMS AND CELLS

These are the main set of rules, regulations, and guidelines regarding GMOs in India. It does a comprehensive job of covering different possible scenarios, gives a framework of suggestions, and establishes an appropriate system at every level of the nation.

2.1.2 THE BIOLOGICAL DIVERSITY ACT (2002)

The Act focuses on the conservation of Biodiversity in India. It establishes a three-tiered structure at the national, state, and local levels to regulate access to biological resources, protect traditional knowledge, and ensure that local communities and the country benefit from their use.

2.1.3 FOOD SAFETY AND STANDARDS ACT (2006)

FSSA mandates that no GMO or GM-derived food products can be produced without prior approval, regulating the manufacturing, distribution, and sale of genetically modified articles of food. Labelling is compulsory for food containing more than 1% of GE ingredients.

2.1.4 DESTRUCTIVE INSECTS AND PESTS ACT (1914)

This Act allows the Government of India to regulate the import and transport of any substances deemed to have potentially harmful effects/capability to infect plants. Thus, this covers various GMOs which often have the said capacity of harm.

2.1.5 RISK ANALYSIS FRAMEWORK (2016)

The Risk Analysis Framework, especially the Environmental Risk Assessment (ERA) Guidelines for GE Plants, guides the Government of India, through its Regulatory Agencies, to implement the risk analysis of genetically engineered (GE) plants in accordance with its laws and regulations.

2.2 RULES, 1989

2.2.1 SCOPE AND APPLICATIONS

These rules apply to the manufacture, import, and storage of micro-organisms and Gene Technology products. The GMOs cover a wide range of products, including crops, other food products, drugs, diagnostic aids, etc. The rules are automatically applied to any new genetic engineering technology.

2.2.2 DEFINITIONS

- **Biotechnology**: the application of scientific and engineering principles to the processing of materials by biological agents to produce goods and services

- **Cell hybridization**: the formation of live cells with new combinations of genetic material through the fusion of two or more cells by means of methods that do not occur naturally

- **Gene Technology**: the application of the gene technique called genetic engineering, includes self-cloning and deletion, as well as cell hybridisation

- **Genetic Engineering:** the technique by which heritable material, which does not usually occur or will not occur naturally in the organism or cell concerned, is generated outside the organism or the cell and is inserted into said cell or organism. It shall also mean the formation of new combinations of genetic material by incorporation of a cell into a host cell, where they occur naturally (self-cloning), as well as the modification of an organism or in a cell by deletion and removal of parts of the heritable material.

- **Microorganism**: includes all the bacteria, viruses, fungi, mycoplasma, cell lines, algae, protozoans, and nematodes indicated in the schedule and those that have not been presently known to exist in the country or have not been discovered so far.

2.2.3 COMPETENT AUTHORITIES

The 1989 rules established six authorities to ensure proper execution of rules and granted them the appropriate judicial power to regulate and assign penalties in case of non-compliance.

2.2.3.1 RECOMBINANT DNA ADVISORY COMMITTEE (RDAC)

Functioning under the DBT, this committee reviews developments in Biotechnology at the national and international levels and periodically recommends suitable and appropriate safety regulations for India.

2.2.3.2 REVIEW COMMITTEE ON GENETIC MANIPULATION (RCGM)

Functioning under the DBT, the RCGM plays a more operational role in ongoing projects and activities involving genetically engineered organisms/hazardous microorganisms. It brings out manuals of guidelines specifying procedures for regulatory processes in experiments involving GMOs or GE.

2.2.3.3 GENETIC ENGINEERING APPROVAL COMMITTEE (GEAC)

The committee functions as a body under the Ministry of Environment, Forest and Climate Change for approval of activities involving large-scale use of hazardous microorganisms and recombinants in research and industrial production from the environmental angle. It is also responsible for the approval of experimental field trials involving GMOs.

2.2.3.4 INSTITUTIONAL BIOSAFETY COMMITTEE (IBSC)

Research Institutes carrying out GMO-related work are mandated to form an Institutional Biosafety Committee (IBSC). The committee should include the Head of the Institution, Scientists engaged in DNA work, a medical expert, and a nominee of the DBT. The IBSC is responsible for coming up with and renewing an on-site emergency plan according to the guidelines of the RCGM.

2.2.3.5 STATE BIOTECHNOLOGY CO-ORDINATION COMMITTEE (SBCC)

The committee shall exist in the states wherever necessary. The Committee shall periodically review the safety and control measures in the various industries/institutions handling genetically engineered organisms/hazardous microorganisms and take actions if necessary.

2.2.3.6 DISTRICT LEVEL COMMITTEE (DLC)

It operates under the District Collectors to monitor the safety regulations in installations engaged in the use of genetically modified organisms/hazardous microorganisms and their applications in the environment, similar to the SBCC, but at a district level.

The RDAC is advisory in function, the IBSC, RCGM and GEAC are of regulatory function. SBCC and DLC are for monitoring purposes. Central Compliance Committees are also set up for monitoring of field trials.

2.2.4 CLASSIFICATION

Microorganisms or genetically engineered organisms, products, or cells shall be dealt with under two major heads: animal pathogens and plant pests.

Microorganisms are classified into five categories

1. Bacterial Agents
2. Fungal Agents
3. Parasitic Agents
4. Viral, Rickettsial, and Chlamydial Agents
5. Special Category

2.2.5 APPROVAL, RESPONSIBILITIES, PROHIBITIONS, AND PENALTIES

2.2.5.1 APPROVAL PROCEDURES

- Commercial use of GMOs requires a license issued by the GEAC.
- The IBSC can carry out restricted experiments outside laboratory areas for educational purposes.
- The validity of GEAC approval is for 4 years with provision for renewal of up to 2 years at a time.
- The GEAC can possibly revoke any approval in light of new information.

2.2.5.2 RESPONSIBILITIES

- The occupier of the IBSC is required to provide an on-site emergency plan to the GEA, and make it available to the SBCC and DLC.
- An approval requires the requisite information, enough experimental data for validity and safety reasons.
- The applicant has to pay for the examinations carried out by the GEAC.

- The person seeking approval has to provide any new information that comes up during the duration of the project.
- The developer of the product, if any, is responsible for demonstrating its safety thoroughly.

2.2.5.3 PROHIBITIONS

- The import, export, transport, manufacturing, sale and use of any GMOs or GMO-derived substances (and hazardous microorganisms) can proceed only with the approval of the GEAC.
- Research involving GMOs is allowed only in laboratory areas notified by the MoEF&CC under the EPA, 1986.

2.2.5.4 PENALTIES

- The DLC or SBCC may take measures against the person who is responsible, in case of non-compliance.
- In cases where immediate interventions are required in order to prevent damage, the DLC or SBCC may take the necessary steps without issuing any orders or notice. The expenses for this purpose are to be paid by the person responsible.
- The SBCC/DLC may take samples for a more detailed examination of organisms and cells.
- Other Government authorities can assist the SBCC/DLC to carry out its instructions.

2.2.6 GUIDELINES

There are several GMO-relevant general guidelines. These are as follows:

- Recombinant DNA Safety Guidelines, 1990
- Recombinant DNA Safety Guidelines and Regulations, 1994
- Revised Guidelines for research in transgenic plants & Guidelines for toxicity and allergenicity evaluation of transgenic seeds, plants, and plant parts, 1998
- Guidelines for generating Pre-clinical and clinical data for rDNA Vaccines, Diagnostics and other Biologicals, 1999
- New Industrial Policy & Procedures, 1991
- Seeds Rules, 1968
- Seeds (Control) Order, 1983
- Seeds Policy 1988 & 2002
- Plant Quarantine Order 2003
- Protection of Plant Varieties and Farmers' Rights Regulations, 2006
- Guidelines & Standard Operating Procedures (SOPs) for Confined Field Trials of Regulated GE Plants, 2008
- Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants (by ICMR), 2008
- Protocols for Food and Feed Safety Assessment of GE Crops, 2008

2.2.7 ENFORCEMENT AND SYSTEM PREPAREDNESS

The enforcement of these various rules and guidelines are carried out by different ministries.

- Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare

- Department of Food and Public Distribution, Ministry of Consumer Affairs. Food and Public Distribution
- Department of Consumer Affairs, Ministry of Consumer Affairs. Food and Public Distribution
- Department of AYUSH
- Department of Commerce, Ministry of Commerce and Industry
- Department of Health Research, Ministry of Health and Family Welfare
- National Biodiversity Authority of India
- Food Safety and Standards Authority of India
- Indian Council of Medical Research
- Indian Biosafety Knowledge Portal
- Central Drugs Standard Control Organization

3. INTERNATIONAL CONVENTIONS AND GUIDELINES

3.1 CONVENTION ON BIOLOGICAL DIVERSITY

The Convention, which is a legally binding agreement, was opened at the Earth Summit in Rio de Janeiro in 1992 and entered into force in 1993. It has three main goals:

- The conservation of Biological Diversity
- The sustainable use of its components
- Fair and equitable sharing of benefits arising from genetic resources.

The Biological Diversity Act, 2002 (and the subsequent Biological Diversity Rules, 2004) of the Indian Government was enacted to ratify the CBD.

3.2 CARTAGENA PROTOCOL ON BIOSAFETY

The Cartagena Protocol to the Convention on Biological Diversity was adopted on 29 January 2000 and entered into force on 11 September 2003. It is an international agreement which aims to ensure the safe handling, transport and use of living modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks to human health. The protocol makes it possible to derive maximum benefit from biotechnology, while simultaneously reducing the risks posed to the environment and the exposed surroundings; in accordance with the goal of conserving biodiversity. It was the driving force for the establishment of GMO policies in many countries.

3.3 NAGOYA PROTOCOL ON ACCESS AND BENEFIT SHARING

It is an international treaty adopted under the CBD in 2010. It has over forty articles establishing a framework for the fair and equitable sharing of benefits and knowledge arising from the study and research of genetic resources. It greatly helped lay down regulations for both the providers and users of genetic resources.The Protocol also has provisions in place regarding access to traditional knowledge of genetic resources held by indigenous and local communities, empowering these communities to benefit from the use of their knowledge, innovations and practice.

3.4 ORGANISATIONS AND OTHER AGREEMENTS

- Food and Agriculture Organization (FAO)
- World Health Organization (WHO)
- Codex Alimentarius Commission, Organisation for Economic Co-operation and Development (OECD)
- Biological Weapons Convention
- International Society for Stem Cell Research (ISSCR)
- World Organization for Animal Health

4. DISCUSSION OF GMO POLICY IN INDIA

4.1 KEY FEATURES

The 1989 rules and other relevant acts/guidelines provide ample opportunity for the adoption of new biotechnologies, although the approval is on a case-by-case basis. India was one of the first countries to create a biosafety regulatory system. The document does a good job at classifying the different kinds of microorganisms and GMOs, and assigning them an appropriate risk category, following the conventions set internationally.

The data requirements for the release of any GMO are very extensive and rigorous, with scrutiny at every step of the way. Active engagement at district level greatly aids the hierarchical review system.

It provides appropriate guidelines for the use/import/export and storage of hazardous microorganism/genetically engineered organisms and cells. It has done a commendable job at establishing an initial system of GMO regulation and, in general, was well thought out along with the liberalization of India in the later years.

4.2 DRAWBACKS

While the GMO policies in India established primarily in 1989 created a comprehensive framework of navigating different possible scenarios regarding GMOs concordant to the

standards of the time, it is imperative to recognize that both the capacities of genetic engineering and the worldview of GMOs have changed *significantly* over the last 35 years.

The present rules include various authorities, departments and rules/guidelines/acts. While they cover the legal and bureaucratic aspects of GMO use and/or production well, it is difficult to not notice that they're simultaneously vague and complicated. These result in implementation gaps, scientific challenges and public trust issues.

Everything is done on a case-by-case basis, which, admittedly, is important for extreme cases, but is otherwise a major problem for uniformity. The case-by-case approach can slow down the process of approvals and lead to wastage of time.

One stark feature to be noticed is the limited public engagement. Public awareness is not a priority and this could potentially add to the general distrust of GMOs. Provisions to conduct large scale surveillance and studies to assess the effects of GMOs on biodiversity, public health etc. are minimal to none.

There is an urgent need for an update of policy, as evident by the landmark GM Mustard case of 2024. The judges of the Supreme Court had contrasting opinions on the decision of the GEAC's clearance to release GM Mustard. This was based on the lack of proper studies of the crop's effects in India (the studies were largely done outside India). The SC directed the Government to formulate a comprehensive national policy on GM crops, involving all stakeholders, to address regulatory gaps and ensure public participation.

Most of the regulation is through the 1989 Rules which, by itself, is not a proper Act. There is only one body of rules governing both GMOs and hazardous microorganisms. Establishing separate legislative entities, preferably Acts, for them can potentially ensure increased and efficient GMO regulation.

4.3 COMPARISON WITH GMO POLICIES OF OTHER COUNTRIES

	USA	Brazil	Argentina	India	Canada	China	EU
Use of Existing Legislation	Yes	No	Yes	Yes	Yes	No	No
New Legislation	Addendums and regulations	Yes	Addendums, resolutions and regulations	Addendums and regulations		Yes	Yes
Agencies Involved	USDA, EPA, FDA	National Technical Commission	Secretariat of Agriculture, Fisheries and Foods	Ministry of Environment and Forests, Department of Biotechnology	Canadian Food Inspection Agency, Health Canada, Environment Canada	Unknown	Authorities of Member States, European Commission
Products Covered	GMO Plants as Food, Potential Plant Pests. Plants engineered to produce	All genetically modified organisms	All genetically modified organisms	All genetically modified organisms and products thereof	Plants with novel traits	Unknown	All genetically modified organisms; all novel foods and novel food ingredients

	insecticide/ pesticides						
Transparency	Yes	Yes	Yes	Yes	Yes	Unknown	Yes
Public Participation	Limited	No	No	Minimal	No	Unknown	Limited
Consultation with Independent Experts	Yes	Yes	Yes	Yes	Yes	Unknown	Yes
Post Approval Review	Limited	Limited	Minimal	Yes	Yes	Unknown	Yes
Enforcement Authority	Limited	_____	Present and Functional	Present and Functional	Present and Functional	Concerned Admin Depts.	Present and Extensive

1

[1] Adopted from *Genetically Modified Organisms in India: Regulatory Policies, Comparison with Global Policies and Suggested Revisions*, Team iGEM IISER Bhopal, 2020

4.4 RECOMMENDATIONS

We propose a few suggestions for reform of the existing rules, to ensure a more accessible policy, flexible and robust at the same time.

- Creation of a single Act concerning **only** GMOs and GE.
- Increased transparency and public participation by creating provisions or rules that mandate the government to make information related to GMO research happening under their jurisdiction public.
- Clear labelling of GMO products to make the consumers cognizant of the type of products they consume.
- A comprehensive risk assessment or calculation system, to ensure uniformity of the classifications used for all appeals of projects concerning GMOs.
- A more streamlined process for review, approval, inspection, and possible removal of a project. This can be achieved by making a more centralized version of the 1989 rules, instead of having different departments involved and sections in relevant acts.
- Involving more scientists, ethicists, relevant stakeholders in the decision-making processes, seeking their feedback continuously and implementing their suggestions.
- Establishment of annual review meetings and comprehensive reports including all the stakeholders, to be made public, as part of increasing transparency.
- Establishment of a GMO awareness cell where people can post their concerns.

SECTION TWO

PROPOSAL OF NOVEL RISK ASSESSMENT SYSTEM FOR GENETICALLY ENGINEERED MICROORGANISMS

5. GENETICALLY MODIFIED MICROORGANISMS

5.1 NEED FOR RISK ASSESSMENT SYSTEM TAILORED TOWARDS GENETICALLY ENGINEERED MICROORGANISMS

Most legislative policies in the country are tailored towards GMO crops and other products produced by plant-based GMOs. However, academia and industry circles are gradually introducing Genetically Engineered Microorganisms (GEMs) into the mix. These microorganisms can be used for an equally vast array of applications, and may even enjoy higher ease in mass-scale translation due to the typically persistent and robust nature of microorganisms.

There is a severe lack of policies and executive framework in this expanding area of research and application. This lag is already proving detrimental to the smooth advancement of the field, with two-fold consequences:

1. Researchers face insurmountable hurdles in their quest to engineer microorganisms for various purposes. They are unable to employ rigorous testing and demonstrate their work to the general public, which increases misinformation and mistrust in the masses.
2. Increased levels of opposition to GEMs reinforces existing lacking and restrictive laws, and actively hinders the formation of newer ones by people in positions of power who do not understand the technology and employ fearmongering as a political tactic.

It is evident that this is a perpetual self-serving cycle.

On the flip side of the coin, it would be irresponsible to assert that GEMs are entirely without risk. However, to use this possibility as a weapon against reasonable research and case studies leaves us wanting for proper data. With the data that we do have, we have compiled a list of common genetic engineering techniques and the reasonable risks that can be anticipated during use. For the purposes of the document, laboratory safety has not been considered a top priority.

5.2 DIFFERENT GUIDELINES FOR DIFFERENT MICROORGANISM ENGINEERING TECHNIQUES: IS THERE A BETTER APPROACH?

Different genetic engineering techniques have different levels of risk in terms of biosafety, biosecurity, and dual-use research concerns. There are an impractical multitude of factors to be considered when discussing risk levels. A singular document can never encompass the intricacies of the field, and thus should only be taken as lubricant, oiling the critical thinking machine of the masses.

Disclaimers aside, this extensive classification and differentiation is why a comprehensive system is vital to ensure that we cover our bases when it comes to upholding research standards and predicting outcomes.

There exist many genetic engineering techniques, each one better than the last. We have Meganucleases in the initial generation of genomic-editing tools. They are a type of endonucleases that can recognize and cleave specific long DNA sequences. In the second

generation, we have tools like Zinc Finger Nucleases (ZFNs) and Transcription activator-like effector nucleases (TALENs). CRISPR-Cas9 or CRISPR with similar proteins and other technologies constitute the third generation of genetic engineering techniques, and is presently the most efficient, precise and economical technology.

It is worthy to note here that the final product of a given modification, rather than the modification method or process itself, is more likely to result in an unintended effect. However, we will still touch upon the consequences of the most well-characterized tools to gain an understanding of the sort of dangers we're dealing with in order to effectively mitigate them.

Technique	Working	Risks to be assessed
Agrobacterium-mediated Transformation	Uses a natural bacterium to shuttle a new gene into a plant's genome.	The primary risk is that the gene might get inserted in the wrong place. This could disrupt the function of an existing, essential gene or activate a dormant one, leading to unintended traits.
Biolistics (Gene Gun)	Physically shoots tiny metal particles coated with DNA directly into plant cells.	This method is less precise and can cause significant damage to the target cell's DNA. It often results in multiple or fragmented copies of the gene being inserted, which makes the outcome less predictable and can lead to unstable gene expression.

Protoplast Fusion	Strips the cell walls from two different plant cells and encourages them to merge into one hybrid cell.	Fusing entire genomes from different species is a massive genetic overhaul. The resulting hybrid is often unstable, and it can be difficult to predict which traits will be expressed or lost. Many fused cells simply aren't viable.
Transposons (Jumping Genes)	Uses mobile DNA sequences ("jumping genes") to insert a new gene into the host's genome.	Transposons insert themselves randomly, which carries a high risk of disrupting important native genes. They can also jump out again or move to a new location in later generations, making the genetic modification unstable.
Microinjection	Uses a microscopic needle to inject DNA directly into the nucleus of a single cell.	The physical act of injection can easily damage or kill the cell. It is a technically difficult process with a very low success rate, and even when successful, there's no guarantee the injected DNA will integrate properly into the genome.
Electroporation	Applies an electrical field to cells to create temporary pores in their membranes, allowing new DNA to enter.	The electric shock is stressful and can kill many of the cells. For those that survive, the DNA enters but integrates randomly and often inefficiently into the genome, carrying

		the same risks of disrupting existing genes as other non-targeted methods.
CRISPR-Cas9	A highly precise molecular tool that acts like "genetic scissors" to find and edit a specific DNA sequence.	Although it's the most precise tool, CRISPR isn't perfect. It can sometimes make cuts at unintended DNA sites that look similar to the target, leading to unwanted mutations. There's also ongoing research into potential large-scale, unintended DNA deletions.
Zinc-Finger Nucleases (ZFNs)	An older gene-editing tool that uses engineered proteins (zinc fingers) to bind to and cut specific DNA sequences.	ZFNs are less precise than CRISPR and have a higher likelihood of making off-target cuts. The proteins themselves can also be toxic to the cells, leading to a lower success rate and a higher chance of cell death. Can induce non-specific mutations,
TALENs	Another gene-editing tool similar to ZFNs, but uses a different type of protein that can be easier to engineer.	TALENs are generally more precise than ZFNs but still carry a risk of off-target mutations. They are also large and complex proteins, which can make them difficult to deliver into cells effectively.

Transduction	Recombinant DNA is introduced to cells.	

Clearly, some risks and consequences are common across techniques. We will therefore use them and their consequences as parameters when building the risk assessment model.

- The gene might get inserted into the wrong place, causing off-target issues.
- Unintended spreading via horizontal and vertical gene transfer.
- Broad ecological consequences through inter-species and inter-individual interactions.
- If developed for consumption, they could potentially prove hyperallergenic or even toxic to certain individuals.

5.3 CLASSIFICATION

The applications of GEMs range from diagnostics, chemical production, agriculture, bioremediation, therapeutics, and the like. For the purpose of building our risk classification system, we categorize the GEMs into two domains based on the domain of application:

1. The GEMs produce the intended product.

   The modified organism produces a metabolite, secretory molecule, or otherwise generated substance that is collected for use. These are more likely to be in a contained setting for industrial production, or a specific ecological niche. Loss of function and gain of function mutation is of utmost possibility here, while horizontal gene transfer may not directly apply.

2. The GEMs are the intended product.

   The modified organism is collected for use. Bt cotton is the best crop example for this category. The actual modified organism performs an action or has an intrinsic property that makes its production desirable. Then, it proliferates. These may have much higher bearing in terms of accidental and long-term ecological consequences.

   This crude intuitive framework demonstrates a critical failure of the current system—to take into account the vastness of the risks and consequences, and just how easy it is for GEMs to fall within one or more of these categories. One of our biggest criticisms in Section 1 of the report was the case-by-case way in which GEMs are handled, leading to excessive bloated regulations going nowhere. Risk assessment can instead be streamlined by determining the broad scope of risks, and ranking the GEM's score based on variables like modification technique, delivery mechanism, application area, etc. This will allow researchers to assess themselves the risks they will be working with, and modify their plans and protocols accordingly.

5.4 NOVEL RISK CALCULATION SYSTEM FOR GENETICALLY ENGINEERED MICROBES

In light of all this, we propose a novel four-part classification system that characterizes the risk of the GEM after it has successfully been engineered. The system will have four pillars:

1. **Containment Class**

How hard is it to contain the organism?

This class assesses the ease with which an engineered microorganism may escape biocontainment strategies. It deals primarily with the context, area, and/or environment in which the GEM is deployed. It may help dictate the biocontainment strategies that are required to keep the organism in check. It may be tailored to the resources and containment strategies the individual researcher has at their disposal.

Score	**Description**
1	The organism, to a reasonable degree, does not pose any risk of breaching containment. It requires minimal resources to contain.
2	The organism poses slight risk of breaching containment. It is less predictable, but still reasonably easy to contain.
3	The organism poses risk of breaching containment. Some measures have to be taken to contain the organism in the directed environment.
4	The organism will most likely breach containment. Significant resources have to

	go towards containing the organism.
5	The organism will absolutely breach containment. It requires the highest level of containment procedures and resources towards the same.

It is important to note that a Level 1 Containment Class organism is not automatically "safe". A lethal human pathogen would still be a Level 1 in this Class if it were extremely trivial to contain.

2. Proliferation Class

How quickly, and how far, can the organism spread?

This Class describes the organism's ability to widely proliferate and therefore, indirectly, the rate of proliferation. Depending on the context, it can describe proliferation within and outside containment, and can therefore be used to determine prospective solutions and/or preventative measures accordingly. Similarly, depending on the context, this Class can be affected by environmental conditions, availability of nutrients, presence of other microorganisms, and the like.

Score	Description
1	The known or probable rate of spread is so low as to virtually not be a concern. Containment breaches should pretty much

	clean up after themselves.
2	The known or probable rate of spread is present, but not concerning. The organism does not spread at an alarming rate.
3	The known or probable rate of spread is present. The organism spreads at a noticeable rate.
4	The known or probable rate of spread is present, and concerning. The organism spreads at an alarming rate.
5	The known or probable rate of spread is dangerous. Containment breach would indicate spread on a massive scale.

It is important to note that a Level 1 organism in this Class does not automatically indicate that it is easy to contain OR that it is not dangerous. A non-engineered example could be the influenza virus.

3. **Disruption Class**

How bad can the consequences of release/spreading be?

This category deals with the consequences and implications of the microorganisms, should they ever break biocontainment. This may especially be applicable to pathogens, microbes that produce toxic metabolites, and microbes seeking environmental deployment.

Level	Description
1	The harmful effects of the organism are non-existent to mild. Spreading of the object causes no known harm to biological and/or non-biological systems.
2	The harmful effects of the organism are mild to moderate. Spreading of the object causes some known harm to biological and/or non-biological systems.
3	The harmful effects of the organism are moderate. Spreading of the object causes known harm to biological and/or non-biological systems.
4	The harmful effects of the organism are moderate to severe. Spreading of the object causes significant harm to biological and/or non-biological systems.

	Death may occur.
5	The harmful effects of the organism are extreme. Spreading of the object causes extreme harm to biological and/or non-biological systems. Death and destruction is likely.

4. Characterization Class

How much do we know about the organism?

This Class aims to put into context all the previous classes by assessing our knowledge of the engineered microbe. This will almost entirely depend on the quality and quantity of research carried out in the lab before the organism was officially put into use in the chosen environment. Information and data collected about its behavior, metabolic processes, genetic characterization, etc can help reduce the impact of all three previous classes combined.

Level	Description
1	The organism's genome is sequenced and most of its metabolic processes have been characterized. We anticipate no surprises.
2	The organism's genome is sequenced and some of its metabolic processes have been

	characterized. We anticipate no significant surprises.
3	The organism's genome is at least 50% sequenced and some of its metabolic processes have been characterized. We anticipate some surprises.
4	The organism's genome is not sequenced and very few of its metabolic processes have been characterized. We anticipate significant surprises.
5	The organism's genome is not sequenced and none of its metabolic processes have been characterized. We anticipate many surprises.

5. **Assessment based on release**

While not one of the four main pillars, we are of the opinion that to streamline classification work it is necessary to place each organism into a release environment category. An environment specific committee would oversee the classification and validate a proposal submitted by the individuals studying the GMO. This would ensure that an application is only judged by experts in the field, which would lead to a classification representative of the reality.

The committee would be unique, in that it would include not just academics, but all stakeholders associated with the environment. This is because the civic implications of a GMO must be weighed with as much gravity as the technical and scientific. Any individual on the committee having a conflict of interest would be excluded for a given application. We are working on a system that would be fair to all stakeholders, and allow a replacement committee member to be elected in this scenario. While the best judgement on the technical aspect can only be from scientists, all the individuals in the committee would discuss the implications of a given GMO and provide an independent verdict. After these verdicts, a democratic voting process would take place to decide on whether the application should be approved.

However a clause would allow the scientific committee, on the basis of an internal vote, a veto on the decision. This is to ensure no economic interests on behalf of the non-technical stakeholders would influence the verdict. This system is by no means perfect, but it would definitely be a step up from the current regulatory framework.

5.5 CONCLUSION

After scoring the microorganism in each Class, the researcher can proceed to add up the values to calculate the total score out of twenty.

Score range	Risk level
Score < 5	Minimal risk.

5 < Score < 10	Possible risk.
10 < Score < 15	Significant risk.
Score > 15	Extreme risk.

This is, of course, a rudimentary classification and can currently only predict risk levels through vague scenarios. However, with further work and clearer metrics and definitions, we could have a very valuable handbook on our hands. Such classifications could be used to build a working risk assessment and management system from the ground up, and policies could be put into effect based on the level of risk. We call for action to be taken in this regard by national and international stakeholders everywhere.

REFERENCES

1. *Environmental Protection Act*. 1986.
2. *Rules for the manufacture, use/import/export and storage of hazardous microorganisms/genetically engineered organisms and cells*. 1989.
3. *Convention on Biological Diversity*. 1992.
4. *The Cartagena Protocol on Biosafety*. 2000.
5. *Nagoya Protocol*. 2010.
6. *Recombinant DNA Safety Guidelines.* 1990.
7. *The Biodiversity Act.* 2002.
8. *The Plant Quarantine Order.* 2003.
9. *Food Safety and Standards Act.* 2006.
10. *Gene Campaign vs Union of India case.* 2025
11. *Guidelines on Genetically Engineered Plants Containing Stacked Events.* 2025.
12. Xinxin Li, Yuanjiao Gao, Ziyu Zhang, Wen Deng, Weihua Cao, Xin Wei, Zixuan Gao, Linmei Yao, Shuojie Wang, Yao Xie, Minghui Li, *Biosafety considerations triggered by genome-editing technologies*, Biosafety and Health, Volume 7, Issue 3, 2025, Pages 141-151, ISSN 2590-0536.
13. National Research Council (US) Committee on Identifying and Assessing Unintended Effects of Genetically Engineered Foods on Human Health, *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects,* 2004.

14. Mahdizade Ari M, Dadgar L, Elahi Z, Ghanavati R, Taheri B, *Genetically Engineered Microorganisms and Their Impact on Human Health,* International Journal of Clinical Practice. 2024 Mar 9; 2024:6638269.
15. John Paul C.H.C. , *Regulation of Genetically Modified Organisms in India: A Critical Legal Analysis in the Context of Global Best Practices,* 8 (2) IJLMH Page 4014 - 4025 (2025)
16. Singh, Gurvinder & Budhwar, Vikas & Choudhary, Manjusha & Singh, Sikander. (2022). *Regulations on genetically modified microorganisms and their relation to bioterrorism in India.* Bulletin of Pharmaceutical Sciences. Assiut. 45. 565-584.
17. Ahuja V. *Regulation of emerging gene technologies in India*. BMC Proc. 2018 Jul 19;12(Suppl 8):14.
18. Todi S, Dixson H. (2024, September 13). *People must be at the heart of GMO policies.* Nature India.
19. *Revised Simplified Procedure/Guidelines on Import, Export, and Exchange of Regulated Products.* 2020.
20. *Task Force on "Genome Engineering Technologies and their Applications".* 2014.
21. *Guidelines on Exchange, Import and Export of Genetically Engineered Organisms and Products*. 2015.
22. *Guidelines for the Environmental Risk Assessment of Genetically Engineered Plants.* 2016.
23. *Environmental Risk Assessment of Genetically Engineered Plants: A Guide for Stakeholders and Risk Analysis Framework*. 2016.
24. *The International Genome-Editing Summit.* 2017.

25. *Regulations and Guidelines for recombinant DNA research and Biocontainment.* 2017.

26. *Global Regulatory Framework for Human Genome Editing.* 2021.

27. *Protocols for Food and Feed Safety Assessment of GE Crops*. 2008.

28. *Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants (by ICMR).* 2008.

29. *Guidelines & Standard Operating Procedures (SOPs) for Confined Field Trials of Regulated, GE Plants*. 2008.

30. *Protection of Plant Varieties and Farmers' Rights Regulations.* 2006.

31. *Guidelines for Generating Pre-Clinical and Clinical Data For r-DNA Based Vaccines, Diagnostics And Other Biologicals.* 1999.

32. *Revised Guidelines for research in transgenic plants & Guidelines for toxicity and allergenicity evaluation of transgenic seeds, plants and plant parts.* 1998.

33. *Strategies for Assessing the Safety of Foods Produced by Biotechnology*. 1991.

34. *Seeds Rules.* 1968.

35. *Asilomar Conference on Recombinant DNA*. 1975.

36. *The International Convention for the Protection of New Varieties of Plants.* 1961.