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Scrutinizing India's Regulatory Framework On Gm Crops: Aligning Sustainable Environmental Practices With Food Security Demands

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ABSTRACT

This study rigorously analyses India's regulatory structure for Genetically Modified (GM) crops, emphasising its potential to reconcile environmental sustainability with food security demands. India confronts the simultaneous problem of sustaining an expanding population while safeguarding its diverse biodiversity and ecological systems. Genetically modified crops, regarded as a potential solution for improving agricultural productivity, provide both advantages and hazards. This study assesses the legislative frameworks, policies, and regulatory entities tasked with supervising GM crops, with a special focus on the Genetic Engineering Appraisal Committee (GEAC) and other key authorities. The study examines case studies, including Bt. cotton, to evaluate the actual effects of genetically modified crops on food security and sustainability. Challenges such as public opposition, the deficiencies in risk assessment, and gaps in regulatory enforcement are highlighted. The study concludes with policy recommendations to align GM crop regulation with sustainable Agricultural practices, suggesting reforms to improve biosafety protocols, transparency, and inter-agency coordination.

Keywords: *GM Crops, Food Security,Regulatory Framework, Sustainable Agriculture, Biosafety*

1. INTRODUCTION

Genetically modified (GM) crops signify a pivotal intersection of contemporary biotechnology and agriculture, providing potential remedies for urgent global issues such as food security, climate change, and sustainable development. In India, where agriculture is crucial to the economy and rural life, genetically modified crops have the potential to increase output, improve insect resistance, and diminish reliance on chemical inputs. Nonetheless, their implementation is fraught with controversy, stemming from apprehensions regarding environmental safety, public health, and socio-economic effects on farmers.

Two conflicting imperatives constrain India's regulatory system on GM crops: ensuring food security for its expanding population and preserving environmental sustainability. Various authorities and statutes, such as the Genetic Engineering Appraisal Committee (GEAC), the Environment Protection Act (EPA) of 1986, and the Rules for the Manufacture, Use, Import, Export, and Storage of Hazardous Microorganisms (1989), govern the regulatory framework. These laws seek to evaluate the hazards linked to GM technology, guaranteeing that its use does not jeopardise environmental integrity or public health.

However, despite these mechanisms, the regulatory system has faced criticism for its fragmentation, lack of transparency, and sluggishness in adapting to technological progress. Furthermore, concerns about corporate monopolies and farmer susceptibility fuel public dissent, hindering the integration of GM crops into India's agricultural policy. Achieving equilibrium between promoting innovation and safeguarding environmental and public interests continues to be a primary problem.

This article analyses India's regulatory framework on GM crops, assessing its alignment with sustainable environmental policies and India's food security demands. This will examine the possibility for reforms to establish a more harmonious, transparent, and adaptive regulatory framework that may effectively address the dual objectives of agricultural innovation and environmental sustainability.

2. FOOD SECURITY AND GM CROPS

Food security is a significant concern in India, where a rapidly growing population, varied agricultural conditions, and socio-economic inequality create a complex landscape for ensuring that all citizens have access to sufficient, safe, and nutritious food. In its efforts to enhance agricultural output and address malnutrition, the country may consider GM crops as a viable answer. These GM crops, engineered for attributes such as pest resistance and drought tolerance, are expected to increase yields and boost food quality.

2.1 2.1 FOOD SECURITY- PRESSING ISSUE

As per 1996 World Food Summit "Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition given by Food and Agricultural Organization (FAO) may be used to identify the four basic aspects of food security namely, Food utilisation, physical availability to food, economic accessibility to food, and stability of the other three variables across time(The EC - FAO Food Security Programme & Zezza, 2003).

The global hunger and food insecurity crisis has worsened dramatically since 2015, fuelled by a complex mix of challenges, including the COVID-19 pandemic, armed conflicts, climate change, and widening inequalities. By 2022, nearly 735 million people, around 9.2% of the world's population, were suffering from chronic hunger, a stark increase from pre-pandemic levels in 2019. Even more alarming, approximately 2.4 billion people experienced moderate to severe food insecurity in 2022, meaning they struggled to access enough nutritious food. This number represents an increase of 391 million people compared to 2019.An estimated 2 billion people globally lack regular access to safe, nutritious, and sufficient food. Among the most vulnerable, 148 million children were stunted in 2022, and 45 million children under five were affected by wasting, a severe form of malnutrition. Looking ahead, projections suggest that over 600 million people could still face hunger in 2030, making the goal of eradicating hunger a formidable challenge(Martin, 2023).

For those experiencing moderate food insecurity, daily life often means sacrificing balanced, healthy meals due to financial or resource constraints. The COVID-19 pandemic exacerbated this trend, intensifying malnutritionparticularly among children and reversing years of progress. Compounding this crisis is the war in Ukraine, which has disrupted global food supply systems, creating the largest food crisis since World War II.The growing prevalence of hunger and malnutrition is not just a statistic; it reflects the lived realities of millions who face uncertain access to food, highlighting an urgent need for collective action to build resilient and equitable food systems.

According to the FAO, hunger is a state in which the food a person consumes is insufficient to give them the nutritional energy they need to live a healthy and productive life. The undernourishment indicator shows the general state of food access for the population, whereas stunting and wasting are more specific signs of child malnutrition(*Hunger and Food Insecurity | FAO | Food and Agriculture Organization of the United Nations*, n.d.). Based on the Global Hunger Index (GHI) Severity of Hunger Scale, India's 2024 GHI score of 27.3 is deemed "serious." In the 2024 GHI report, India is placed 105th out of 127 countries, down from 111th in the 2023 report. In India, the incidence of undernourishment is 13.7%, child stunting is 35.5%, child wasting is 18.7%, and the under-five death rate is 2.9%(Index, 2024c).

In the Global Hunger Index 2022, India came in at number 107 out of 121 nations(Von Grebmer et al., 2022), having the highest child mortality rate in the world at 19.3%. A technique for thoroughly assessing and monitoring hunger on a global, regional, and national scale is the Global Hunger Index (GHI). India's hunger situation is considered "serious" with a score of 29.1.Afghanistan is the only nation in Asia after India, coming in at number 109. Neighbouring nations have performed better than India, including Pakistan (99), Bangladesh (84), Nepal (81) and Sri Lanka (64)(Pti, 2022).

It is well known that there is a severe shortage of food to feed the world's population. The issue has been acknowledged at several conferences and seminars on a global scale, but no one has found a satisfactory answer, or the world is just too busy looking for band-aid fixes. The obligation of the international community to assist in the export or import of food cannot be ignored. This won't resolve the issue since food isn't just a product that can be purchased and sold. It goes beyond the nutrients that one takes in.

2.2 2.2 GENETICALLY MODIFIED CROPS/FOODS: A SOLUTION AHEAD

Fundamentally, biotechnology involves applying biological principles to create products and technologies that enhance both the health of the planet and human lives. It uses biomolecular and cellular mechanisms to address practical problems(*BIO*, n.d.). Biotechnology is essential to agriculture because it combines conventional breeding methods with cutting-edge tools to produce or alter goods, enhance crops and livestock, and create microorganisms that are suited to certain agricultural requirements. This creative strategy aids in addressing urgent problems, including environmental preservation, sustainability, and food security.

Modern biotechnology now incorporates genetic engineering technologies, paving the way for advanced innovations and applications.Examples of procedures that fit within the definition of biotechnology include brewing and baking bread,where yeast is a live creature that may be used to generate the desired result(*Biotechnology FAQs*, n.d.).Traditional biotechnology typically relies on using living organisms in their natural form or improving them through selective breeding. In contrast, modern biotechnology often takes this further, involving more intricate modifications of biological systems or organisms to achieve specific outcomes*(NTNU*, n.d.).

Biological entities (plants, animals, or microbes) that have had their genetic material (DNA) changed in a way that does not happen normally through mating and/or natural recombination are known as genetically modified organisms (GMOs). The term "modern biotechnology" or "gene technology" is frequently used, along with other terms like "recombinant DNA technology" or "genetic engineering". It enables the transfer of specific genes from one creature to another, as well as between unrelated species. GM foods are frequently referred to as foods created with or utilising GM organisms(*Food, Genetically Modified*, 2024).

3. INDIA'S LEGISLATIVE FRAMEWORK ON GM CROPS

India's legislative framework for genetically modified (GM) crops aims to reconcile innovation with biosafety and environmental conservation. Regulated chiefly by the Environment (Protection) Act of 1986 and the 1989 Rules for genetically modified organisms, it delineates stringent regulatory procedures for research, testing, and commercialization. Although Bt cotton is the sole genetically modified crop sanctioned for production, the framework illustrates India's prudent strategy in tackling the scientific, ethical, and socio-economic issues linked to GM technology.The following legislations governing GM crops are mentioned below.

3.1 ENVIRONMENT PROTECTION ACT, 1986

The Ministry of Environment, Forestry, and Climate Change has implemented the Environment (Protection) Act, 1986, an umbrella legislation that established a comprehensive framework for the protection and preservation of the environment(Kolady and Herring 2014).Section 6 of the act empowers the central government to establish the procedure and safeguard for handling the hazardous substances. It can specify procedural safeguards to prevent accidents involving hazardous substance and establish standards to mitigate the repercussions if accidents occur. Furthermore, it can restrict or prohibit the utilization of certain hazardous substances in specific designated locations or industries, ensuring that their utilization does not lead to environmental degradation. Section 8 imposes a duty on individuals handling hazardous substances to take requisiteprecautions to avert environmental pollution and mitigate any harm. The central government can enforce stringent protocols to ensure the safe handling of such materials. Section 25 provides the Central Government with the authority to frame rules necessary for implementing the provisions of the Act, including those related to the regulation of hazardous substances. This section empowers the government to develop detailed guidelines, enforcement procedures, and mechanisms to ensure safe management of hazardous substances, thereby safeguarding the environment and public health.

3.2 RULES FOR THE MANUFACTURE, USE, IMPORT, EXPORT, AND STORAGE OF HAZARDOUS MICROORGANISMS/GENETICALLY ENGINEERED ORGANISMS OR CELLS, 1989 (1989 RULES)

In order to safeguard the environment, nature, and health in relation to the application of gene technology and microorganisms, the Rules for the Manufacture, Use, Import/Export, and Storage of Hazardous Microorganisms, Genetically Engineered Organisms, or Cells (Rules, 1989)(MoEF Notification 1989) have been notified under the Environment (Protection) Act, 1986, in pursuanceof sections 6, 8, and 25 of the Act. These rules, the most stringent, regulate all activities associated with genetically engineered organisms and their products. In addition, these organisms are subject to additional laws, regulations, and policies.

The Rules of 1989 are comprehensive, covering various activities related to genetically modified organisms (GMOs) and their products, including sale, storage, export, import, production, manufacture, and packaging. These regulations govern research activities and extensive applications of GMOs, encompassing the production, importation, and storage of microorganisms and genetic technology products. They also cover genetically modified organisms, microbes, and cells, as well as any substances, products, and food items in which such cells, organisms, or tissues form a part. Additionally, the rules also extend to emerging gene technologies, including cell hybridisation and genetic engineering, so assuring thorough oversight of all developments in the domain.One of the key aspects of these rules is the requirement to acquire permissions and licenses prior to any manufacturing, usage, or transfer of these organisms. Before initiating activities, entities must conduct comprehensive risk assessments to identify potential hazards and ensure the implementation of appropriate safety measures. This procedure promotes a culture of safety and accountability within organizations that handle these materials.

3.3 THE NATIONAL SEED POLICY, 2002

The National Seed Policy of 2002 in India aims to ensure the prompt accessibility of high-quality seeds at reasonable prices for farmers, with the objective of improving agricultural production and enhancing food security. It promotes the participation of both the public and commercial sectors in seed production, distribution, and research, facilitating the advancement of high-yielding, disease-resistant, and climate-resilient crop varieties. The policy enhances seed commerce by enabling seed exports and permitting the importation of superior varieties to improve the quality of domestic seed inventory while assuring compliance with rigorous quality control protocols via certification and testing standards. The policy is consistent with the Protection of Plant Varieties and Farmers' Rights Act, 2001, which provides legal protection to plant breeders for novel seed varieties and acknowledges farmers' traditional rights to conserve, use, exchange, and sell seeds(Indian Agriculture, n.d.).

The policy acknowledges biotechnology as an essential instrument for enhancing agricultural innovation concerning

genetically modified (GM) crops. It facilitates the development and commercialization of genetically modified crops that exhibit superior characteristics, including increased production, resistance to pests and diseases, and tolerance to unfavourable climatic conditions. The strategy requires a stringent regulatory system to guarantee biosafety, with the Genetic Engineering Appraisal Committee (GEAC) tasked with the approval and oversight of GM crops. This regulatory monitoring seeks to reduce potential environmental and health hazards linked to GM technology, ensuring that the entry of GM seeds into the market adheres to national and international safety standards.

3.4 THE BIOLOGICAL DIVERSITY ACT OF 2002

The Biological Diversity Act of 2002 in India seeks to conserve biological diversity, foster sustainable utilization of its components, and ensure fair and equitable distribution of benefits derived from the use of biological resources and related traditional knowledge. It creates a framework for regulating access to biological resources, therefore aiding in the protection of India's abundant biodiversity from overexploitation and misuse.

The Biodiversity Act tackles the potential impact on biodiversity resulting from the utilisation and release of genetically modified (GM) organisms. According to the Act, prior authorization is necessary for utilizing biological resources for research or commercial purposes, which encompasses the production of genetically modified crops. Under the Act, the National Biodiversity Authority (NBA) plays a crucial role in monitoring the use of biological resources, ensuring that all activities, including genetically modified agricultural research, comply with conservation principles and do not negatively impact the environment or native species.

The Act also supports biosafety protocols for genetically modified crops by including risk assessment and management rules to avoid any negative effects on the ecosystem, such as genetic contamination of wild relatives and the loss of biodiversity. The Biodiversity Act's regulation on GM crops complements India's other biotechnology regulatory framework, including the supervision by the Genetic Engineering Appraisal Committee (GEAC). These rules make sure that the creation and use of GM crops protect biodiversity and are in line with goals for sustainable development(India, 2003).

3.5 THE FOOD SAFETY AND STANDARDS ACT, 2006

The Food Safety and Standards Act, 2006 is crucial in regulating genetically modified (GM) crops in India by supervising GM food products through the Food Safety and Standards Authority of India (FSSAI). The Act ensures that all genetically modified food introduced to the market is safe for human consumption. It requires safety evaluations for GM crops designated for food consumption, and it also addresses labelling obligations to notify consumers regarding GM components. While full guidelines for GM food labelling are still developing, the FSSAI's role in evaluating the safety and quality of GM foods is essential for consumer protection and public health in India.(Parliament of India, 2006)

4. INDIA'S REGULATORY FRAMEWORK ON GM CROPS

India has established a robust and multi-layered regulatory framework to ensure the safe development and responsible use of genetically modified (GM) crops. This framework brings together multiple ministries and regulatory bodies, each with a distinct role in overseeing the research, testing, and commercialization of GM organisms.The 1989 Rules, implemented by the Ministry of Environment, Forest & Climate Change (MoEF&CC), the Department of Biotechnology (DBT) under the Ministry of Science & Technology, and State Governments, serve as the foundation of this system. Under these rules, six competent authorities have been established, each with specific roles and structures. Their functions, which are critical to ensuring the safety and efficacy of GM crops, are outlined in Table 1. This collaborative framework reflects India's commitment to regulating biotechnology responsibly(Ministry of Environment, Forest and Climate Change (MoEFCC) et al., n.d.).

Statutory Committee	Function	Housed at
rDNA Advisory Committee (RDAC)	Review biotechnology developments and suggest appropriate safety guidelines for recombinant DNA research, usage, and applications.	Department of Biotechnology, Ministry of Science and Technology
Institutional Biosafety Committee (IBSC)	Responsible for ensuring adherence to safety guidelines for experimentation at designated location	All organizations engaged in activities involving GMOs
Review Committee on Genetic Manipulation (RCGM)	Review all ongoing rDNA projects and approve experiments falling in risk category III and above; also responsible for bringing out manuals of guidelines for conduct of GMO research and use	Department of Biotechnology, Ministry of Science and Technology
Genetic Engineering Appraisal Committee (GEAC)	Authorized to review, monitor and approve all activities including import, export, transport, manufacture, use or sale of GMOs and products thereof from environment angle	Ministry ofEnvironment, Forest and Climate Change

State Biotechnology Coordination committee (SBCC)	Monitoring and supervision at state level	Concerned State Governments
District Level Committee (DLC)	Supervision and compliance at district level	Concerned State Governments

Table 1

5. CASE STUDY - BT. COTTON IN INDIA

Bt cotton, which is resistant to Lepidopteran pests, was initially introduced in India as a hybrid in 2002 following extensive bio-safety and profitability assessments. After comprehensive testing under the All India Coordinated Cotton Improvement Project (AICCIP) and on agricultural fields, the Indian government sanctioned its commercial production commencing with the 2002 crop season. The initial adoption encompassed 38,038 hectares in 2002-03, which increased to 0.56 million hectares by 2004-05. In 2005-06, there was a substantial increase, attaining 1.3 million hectares—a 160% rise compared to the prior year. By 2006-07, the area increased to 3.72 million hectares. In 2006, India's Bt cotton cultivation exceeded 3.8 million hectares, surpassing China's 3.5 million hectares. In that year, 60% of the entire 6.3million hectares of hybrid cotton in India was Bt cotton, comprising 34% irrigated and 66% rainfed cultivation(Khadi & Central Institute for Cotton Research, 2007). The introduction of Bt cotton in India has substantially aided farmers and the agricultural sector, notwithstanding several concerns. It increased profits by Rs. 1,877 (US$38) per acre and elevated yields by 126 kg/acre, representing increases of 50% and 24%, respectively, in comparison to conventional cotton. This resulted in an 18% rise in yearly consumption expenditures for Bt cotton cultivators, signifying enhanced living standards(Kathage& Qaim, 2012).

The implementation of Bt cotton resulted in a 22-fold growth in India's agri-biotech sector from 2002 to 2011, accompanied by a 212-fold rise in plantings, representing almost 30% of the world's cotton cultivation area. Consequently, India eclipsed China, emerging as a preeminent cotton producer and exporter. Presently, 88% of cotton cultivators, equating to 7 million out of 8 million, cultivate Bt cotton annually. The crop has increased yields by 31% and decreased insecticide usage from 46% to 21%, resulting in an additional US$11.9 billion in cotton revenue. Thus, the interval from 2002 to 2011 is frequently termed the "white gold" era for India's genetically modified cotton sector(James, 2011).

Bt cotton confers resistance to significant insect pests, particularly cotton bollworms. Numerous studies indicate that the introduction of Bt cotton diminishes chemical pesticide application and enhances yields in agricultural regions. Several studies indicate that these benefits correlate with enhancements in farm household income and living standards. Increased incomes are typically anticipated to lead to heightened food consumption among impoverished agricultural households. Cotton is a non-food cash crop, rendering its nutritional impact questionable(Qaim &Kouser, 2013).

6. GM CROPS- SUSTAINABLE AGRICULTURE AND FOOD SECURITY

Agriculture confronts significant obstacles in providing food and ensuring nutritional security using sustainable methods. A system of agricultural cultivation known as sustainable agriculture preserves the environment, society, and economy for both present and future generations, ensuring its viability in both the short and long term (Tripathi et al., 2022). The primary objectives of sustainable agriculture are to generate high yields of nutritious crops, utilize environmental resources efficiently with minimal harm, improve societal quality of life through equitable food distribution, and deliver economic advantages to farmers(Tseng et al., 2020).Scientific literature has extensively acknowledged these objectives, as producing substantial quantities of food with minimal environmental degradation poses significant challenges.Nonetheless, a significant advancement has occurred in agriculture via plant genetic manipulation. Plant biotechnology has produced products that have enabled the agricultural sector to get increased yields in a more sustainable fashion.

In 2015, the Sustainable Development Goals (SDGs) were launched. The primary objectives of the 17 Sustainable Development Goals (SDGs) were to improve human health, eliminate poverty, and improve food security. All Sustainable Development Goals (SDGs) have a target completion date of 2030. The successful attainment of these critical and valued objectives necessitates significant usage of technology and innovation. Since the mid-20th century, advancements in plant breeding have led to efficient food production systems(Smyth, 2022).Advancements in agricultural biotechnology via the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR/Cas) system enable gains in crop output, nutritional value, and diminished environmental impacts(J. N. Tripathi et al., 2021). This signifies the prospective function of genome editing technologies and underscores their crucial contribution to attaining the three fundamental Sustainable Development Goals (SDGs). The CRISPR/Cas9 method boosts sustainability and improves global food security in multiple ways.

Many researchers examine the environmental safety of genetically modified crops. The European Union (EU) financed about 300 million EUR in 130 research initiatives. The research period spanned over 25 years, culminating in the conclusion that GM crops are not more hazardous than conventionally bred plants(European Commission, 2010). Genetically modified crops engineered for input features like insect resistance and herbicide tolerance have diminished agriculture's environmental impact by promoting sustainable agricultural techniques(Brookes & Barfoot, 2015). Furthermore, the genetic alteration of crops represents a logical extension of the selective plant breeding that humans have practiced for millennia. It leads to the preservation of the environment and plant biodiversity, facilitating their integration into sustainable food production systems.

Klumper and Qaim conducted a meta-analysis of the preliminary data acquired from farm surveys and field trials in several regions globally. It suggested that the insect resistance of GM crops has reduced pesticide application by 36.9%(Klümper& Qaim, 2014).

7. CHALLENGES AND CRITICISM OF THE CURRENT REGULATORY FRAMEWORK

The existing regulatory system for genetically modified (GM) crops in India encounters numerous problems and critiques. These difficulties arise from technical, policy, governance, and socio-economic factors.

The regulatory framework for GM crops in India is marked by fragmentation and complexity, hindering its efficacy. Various entities, including the Genetic Engineering Appraisal Committee (GEAC), the Review Committee on Genetic Manipulation (RCGM), and state governments, have overlapping responsibilities in the regulation of GM crops, resulting in inefficiencies and ambiguity. The lack of a cohesive policy or comprehensive legislation pertaining to biotechnology or genetically modified organisms contributes to the uncertainty and inconsistency in governance.

The decision-making process is frequently condemned for its sluggishness and lack of transparency. Regulatory permissions may take years to obtain, causing frustration among stakeholders, including developers and farmers. Moreover, restricted public access to essential data, such as field trial outcomes and scientific evaluations, undermines confidence in the system. This absence of openness intensifies the difficulties encountered by regulatory authorities.The existing system currently limits public engagement and awareness. Decision-making rarely involves stakeholders, particularly farmers and consumers, and there is insufficient communication about the advantages and disadvantages of GM crops. Consequently, pervasive disinformation and scepticism endure.

One significant obstacle is the opposition from state governments. Due to agriculture being a state topic, some states resist field testing of GM crops despite obtaining central government approval, resulting in regulatory impasses and postponed adoption.The post-release monitoring measures for genetically modified crops are inadequate. The limited emphasis on evaluating the long-term environmental and health effects of these crops creates apprehensions regarding their safety and sustainability.

8. REFORM PROPOSALS FOR ALIGNING GM CROP REGULATIONS WITH SUSTAINABILITY AND FOOD SECURITY

Reforming India's regulatory framework for GM crops is essential to reconcile it with sustainability and food security objectives. A comprehensive statute is necessary to create a cohesive framework and facilitate approvals via a single-window clearance procedure. This should be supplemented with procedures to harmonize state and central policy, ensuring more effective cooperation and averting regulatory impasses. Prioritizing transparency and public involvement necessitate the accessibility of biosafety data, the inclusion of stakeholders such as farmers and scientists in decision-making processes, and the initiation of awareness campaigns to inform the public about genetically modified crops. Enhancing infrastructure and capacity is similarly crucial, necessitating investments in contemporary testing facilities, post-release monitoring systems, and training programs for regulatory authorities.

Public-private partnerships should promote research and development, concentrating on genetically modified crops that tackle local agricultural issues like drought and insect resistance while safeguarding indigenous biodiversity. Socio-economic safeguards are essential for protecting small farmers by guaranteeing affordable access to genetically modified seeds, thwarting corporate monopolies, and implementing crop insurance programs. Ecological sustainability must be addressed through the incorporation of biodiversity impact assessments, the promotion of crop variety, and the integration of genetically modified crops with sustainable techniques such as integrated pest management (IPM).

India's regulatory framework must correspond with international protocols, guaranteeing compliance with the Cartagena Protocol and harmonizing standards to improve trade opportunities. Accountability systems, including independent monitoring committees and regular regulatory assessments, must be instituted to guarantee transparency and responsiveness to scientific and technological breakthroughs. These reforms will allow India to leverage the potential of GM crops to achieve its food security and sustainability goals while preserving ecological and socio-economic integrity.

9. CONCLUSION

India's regulatory framework for genetically modified crops necessitates essential reforms to adequately reconcile sustainable environmental policies with increasing food security requirements. The existing system, marked by inefficiencies, disjointed governance, and restricted public engagement, is inadequate for fully using GM technology. A revamped framework must emphasize transparency, inclusion, and coherence, supported by strong infrastructure and scientific competence.

Comprehensive legislation is crucial for streamlining regulating processes, removing redundancies, and harmonizing centre and state policy. Unrestricted access to biosafety data and comprehensive stakeholder involvement can achieve transparency, allowing farmers, scientists, and consumers to participate in decision-making processes. Investment in advanced testing facilities, post-release monitoring systems, and capacity-building initiatives is essential for ensuring thorough biosafety evaluations and the effective assessment of long-term effects.

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