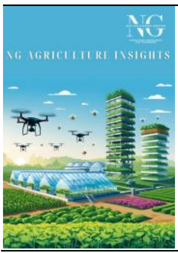

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Genetically Modified Crops in India: A SWOT-Based Assessment of Scientific, Regulatory and Socio-Political Barriers

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ABSTRACT

The adoption of genetically modified (GM) crops remains one of the most contested issues in global agriculture. While countries such as the United States, Brazil, and China have embraced GM technologies, India has maintained a highly precautionary stance, approving only Bt cotton for commercial cultivation since 2002. This article examines the Indian GM crop debate through a SWOT (Strengths, Weaknesses, Opportunities, and Threats) framework. The strengths of GM crops include higher yield potential, resistance to pests and diseases, reduced pesticide use, climate resilience, and nutritional biofortification. However, India's internal weaknesses—such as inadequate biosafety infrastructure, fragmented regulation, limited transparency in field trials, reliance on multinational seed corporations, and knowledge gaps among farmers and consumers—have hindered progress. Despite opportunities for enhancing food security, reducing import dependence, and strengthening biotechnology leadership, the country faces persistent threats, including biodiversity loss, gene flow to wild relatives, ethical and cultural opposition, restrictive trade regimes, and judicial activism. Case studies of Bt cotton, Bt brinjal, and GM mustard illustrate the complex interaction between science, politics, and law. The analysis concludes that advancing GM crops in India requires stronger biosafety systems, regulatory coherence, public engagement, and evidence-based policymaking to balance innovation with ecological and social safeguards.

Keywords: biosafety regulation, genetically modified crops, India, SWOT analysis

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1. INTRODUCTION

The adoption of genetically modified (GM) crops has been one of the most contested technological transitions in agriculture over the last three decades. Proponents argue that GM crops increase yields, enhance pest and disease resistance, reduce pesticide use, and improve nutritional quality, making them essential for ensuring food security in the face of climate change (James, 2010; Brookes & Barfoot, 2018). For example, the United States, Brazil, Argentina, and Canada have widely commercialized GM soybean, maize, and cotton, collectively representing more than 80% of global GM crop cultivation (ISAAA, 2020). In contrast, opponents raise concerns regarding ecological risks, such as biodiversity loss, gene flow to wild relatives, and the emergence of super-pests (Gurian-Sherman, 2009; Nodari & Guerra, 2015). Additionally, socio-economic issues such as corporate control over seeds, farmer indebtedness, and consumer resistance fuel political debates, particularly in developing nations (Shiva, 2016; Scoones, 2008).

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Europe illustrates a strong precautionary approach: most EU countries restrict cultivation despite permitting imports for animal feed, citing uncertainty over long-term environmental and health risks (Davison, 2010). Developing countries remain divided — Brazil and China allow commercial planting, while others, including India and many African nations, have imposed bans or moratoria due to socio-political resistance (Falkner, 2014). Thus, global debates reveal a deep divide between techno-optimist narratives of agricultural modernization and precautionary, ethical, and socio-economic critiques.

India began GM crop trials in the late 1990s, primarily focusing on cotton. In 2002, Bt cotton became the first and only GM crop commercially approved in India, engineered with Bacillus thuringiensis genes to resist bollworm infestations (Qaim & Zilberman, 2003). Studies reported yield gains and reduced pesticide use, yet also noted regional disparities, secondary pest outbreaks, and farmer distress linked to rising input costs (Stone, 2011; Gutierrez et al., 2015).

In 2010, the Genetic Engineering Appraisal Committee (GEAC) recommended commercial release of Bt brinjal, developed by Mahyco in collaboration with Indian public institutions. However, the Ministry of Environment and Forests (MoEF) imposed a moratorium following widespread protests, concerns over biosafety testing, and opposition from civil society and state governments (Herring, 2015).

The most recent controversy involves GM mustard (Dhara Mustard Hybrid-11 or DMH-11), developed by Delhi University researchers. While GEAC recommended its release in 2017 and again in 2022, opponents including farmer unions, environmental groups, and scientists have challenged it in the Supreme Court, citing inadequate safety data, risks to pollinators, and seed sovereignty concerns (Kumar et al., 2019; Jaganathan et al., 2023).

India's regulatory framework for GM crops is multilayered, primarily overseen by the Genetic Engineering Appraisal Committee (GEAC) under the Ministry of Environment, Forest and Climate Change (MoEFCC). GEAC evaluates biosafety data, environmental risks, and socio-economic impacts before recommending approvals, but the final decision rests with MoEFCC, reflecting a precautionary policy stance (Gupta & Chandak, 2005).

The judiciary has become a significant arbiter. The Supreme Court of India has repeatedly intervened, often in response to public interest litigations (PILs). In 2012, the Court's Technical Expert Committee recommended a 10-year moratorium on GM crop field trials until stronger biosafety protocols were established (Kumar et al., 2014). In 2022–23, hearings on GM mustard reflected the Court's role in mediating between scientific bodies, policymakers, and civil society actors (Narayanan, 2023). This dynamic policy landscape reflects India's broader tension: balancing technological innovation for food security against precautionary governance, socio-political resistance, and ecological risks.

2. SWOT ANALYSIS OF GM CROPS IN INDIA

2.1. Strengths: potential benefits of GM crops

Higher yield potential: Genetically modified crops are often engineered to achieve significant yield improvements. Empirical studies on Bt cotton in India revealed notable yield gains in regions severely affected by bollworm infestations (Qaim & Zilberman, 2003). These increases translated into higher farm incomes in the early years of adoption, particularly in states such as Gujarat and Maharashtra (Kathage & Qaim, 2012). While yield impacts have varied across ecological zones, the evidence demonstrates that genetic modification can address yield plateaus in India's stagnating agricultural sector.

Resistance to pests and diseases: Bt crops incorporate genes from Bacillus thuringiensis, producing proteins toxic to major pests. Bt cotton substantially reduced bollworm damage and delayed pest resistance development (Arora & Bansal, 2012). GM technology could be applied to other crops such as rice, brinjal, and maize to confer resistance against stem borers, fruit borers, and fungal pathogens (Sharma et al., 2012). This pest resistance lowers dependence on chemical insecticides and reduces crop losses, which average 20–30% annually in India (Pray et al., 2002).

Reduction in pesticide use: Multiple studies document reduced pesticide application following Bt cotton adoption. For instance, farmers reported a 40–60% decline in pesticide sprays after Bt introduction, leading to lower input costs and decreased exposure to toxic chemicals (Kouser & Qaim, 2013; Bennett et al., 2006). Reduced pesticide intensity also contributes to improved soil and water quality.

Climate resilience and drought tolerance: GM crops are being engineered to withstand abiotic stresses, including drought and salinity. In India, where nearly 50% of agriculture remains rain-fed, drought-tolerant GM maize varieties could help stabilize production (Mittler & Blumwald, 2010). Several experimental programs under Indian public-sector institutes have focused on stress-tolerant rice and mustard, aiming to reduce vulnerability to erratic monsoons and climate change (Ahuja, 2013).

Biofortification (Nutritional GM crops): GM technology also enables biofortification — enhancing the nutritional profile of staple foods. "Golden Rice," fortified with Vitamin A, has been tested in several Asian countries (Potrykus, 2001). In India, transgenic crops enriched with iron, zinc, and essential amino acids are under development, targeting widespread malnutrition (Datta et al., 2012). Such interventions could complement government nutrition programs, especially for marginalized populations.

2.2. Weaknesses: internal challenges within India

Limited biosafety infrastructure: India's biosafety research and testing infrastructure is inadequate compared to global leaders. Rigorous multi-location trials and advanced molecular risk assessments are often lacking, contributing to public distrust (Gupta & Chandak, 2005). Laboratories and state-level monitoring committees face capacity shortages.

Weak regulatory framework and overlapping authorities: The governance system involves multiple bodies, including the Review Committee on Genetic Manipulation (RCGM), the Genetic Engineering Appraisal Committee (GEAC), and MoEFCC. Overlaps, inconsistent decision-making, and political interventions often stall approvals (Herring, 2015). For example, Bt brinjal was cleared by GEAC but blocked by MoEFCC in 2010.

Lack of long-term field trials and transparency: Civil society actors and scientists have criticized insufficient long-term ecological and health studies. Limited public access to biosafety dossiers fuels suspicions about corporate influence (Kumar et al., 2014). This contrasts with transparent review systems in the US and Canada.

Dependence on foreign seed corporations (Monsanto Case): India's GM cotton sector was dominated by Monsanto, raising concerns about seed sovereignty. Royalty disputes between Indian seed companies and Monsanto highlighted risks of dependence on multinational corporations (Ramaswami, 2014). The GM mustard debate reflects similar fears of corporate control over seeds.

Knowledge gaps among farmers and consumers: A lack of awareness and misinformation about GM crops persist. Farmers often misunderstand technology traits, leading to inappropriate pesticide use or seed-saving practices (Stone, 2011). Consumer skepticism, amplified by activist campaigns, has influenced state governments to resist GM adoption (Scoones, 2008).

2.3. Opportunities: External Factors in Favor

Global precedent: Over 70 countries have adopted GM crops either for cultivation or import (ISAAA, 2020). The United States, Brazil, and Argentina demonstrate how GM adoption can scale national production and export competitiveness. China, despite initial resistance, has recently approved GM maize and soybean. India could learn from these models to balance regulation and adoption.

Food security and nutritional enhancement: India faces the dual challenge of feeding 1.4 billion people and combating hidden hunger. GM crops with yield and nutritional benefits could contribute to food self-sufficiency and reduce reliance on imports (Smyth & Phillips, 2014).

Reducing import dependence: India imports large quantities of edible oil and pulses. GM mustard and GM soybean could reduce this dependence, saving foreign exchange and boosting farmer incomes (Kumar et al., 2019).

Potential biotech leadership in Asia: India possesses a strong public research base, including ICAR and public universities. If governance bottlenecks are addressed, India could emerge as a regional leader in agricultural biotechnology (Chaturvedi, 2007).

Export competitiveness: As global food markets diversify, GM crops could enhance India's competitiveness, provided traceability and segregation systems are developed to meet different market standards (Falkner, 2014).

2.4. Threats: risks and external barriers

Biodiversity loss in a mega-diverse country: India ranks among the top 12 mega-biodiverse nations. Critics warn that GM crops threaten wild relatives through gene flow, particularly in crops such as brinjal and mustard (Nodari & Guerra, 2015). This could undermine agro-ecological farming systems.

Gene flow to wild relatives: Studies highlight risks of outcrossing in mustard and brinjal, where India has diverse landraces (Rao, 2010). Such gene flow may complicate biodiversity conservation.

Ethical, cultural, and socio-political opposition: Resistance to GM crops in India is not only scientific but also cultural and ethical. Many civil society groups frame GM crops as threats to traditional agriculture and food sovereignty (Shiva, 2016). This opposition mobilizes public opinion and influences judicial and political decisions.

Trade barriers: The European Union and several Asian markets maintain strict labeling or outright bans on GM imports. India risks losing access to high-value export markets if GM crops are adopted without proper segregation and traceability (Davison, 2010).

Judicial activism & civil society protests: The Supreme Court's involvement has added uncertainty. Repeated litigation has delayed GM mustard approval, while civil society protests amplify resistance (Narayanan, 2023). These factors create a risk-averse political climate.

The SWOT analysis reveals that GM crops present clear scientific and economic strengths for India — higher yields, reduced pesticide use, and potential nutritional gains. However, domestic weaknesses in biosafety infrastructure, regulatory coherence, and farmer/consumer knowledge have created roadblocks. While global opportunities highlight the potential for India to lead in biotechnology and reduce import dependence, threats in the form of biodiversity concerns, socio-political resistance, and trade barriers keep India's policy stance highly restrictive.

Table 1: Chronology of GM crop approvals and bans in India

Year	Crop	Decision	Authority	Outcome
2002	Bt Cotton	Approved	GEAC	Commercial release
2010	Bt Brinjal	Approved by GEAC, banned by MoEFCC	GEAC/MoEFCC	Moratorium imposed
2017	GM Mustard (DMH-11)	Recommended	GEAC	Approval stalled
2022	GM Mustard	Recommended	GEAC	Pending Supreme Court decision

Table 2: SWOT matrix of GM crops in India

Strengths	Weaknesses	Opportunities	Threats
Higher yields	Weak biosafety capacity	Global precedent	Biodiversity loss
Pest resistance	Overlapping regulators	Food security	Gene flow
Reduced pesticides	Dependence on MNCs	Import substitution	Cultural opposition
Climate resilience	Poor transparency	Biotech leadership	Trade barriers
Biofortification	Knowledge gaps	Export competitiveness	Judicial activism

Table 3: Global GM adoption vs India

Country	% of Cropland under GM	Key Crops	Policy stance
USA	~70%	Maize, Soybean, Cotton	Pro-GM
Brazil	~65%	Soybean, Maize, Cotton	Pro-GM
China	Limited (pilot)	Rice, Maize	Cautious adoption
India	<7% (Bt cotton only)	Cotton	Restrictive

3. CASE STUDIES

3.1. *Bt Cotton*

Bt cotton, introduced in 2002, remains the only GM crop approved for commercial cultivation in India. Multiple studies demonstrated initial yield increases, reduced pesticide use, and higher farmer incomes (Qaim & Zilberman, 2003; Kathage & Qaim, 2012). However, secondary pests like whitefly later emerged, leading to renewed pesticide dependence in some states (Kranthi & Stone, 2020). Despite mixed outcomes, Bt cotton's adoption exceeded 90% of India's cotton area, showing strong farmer demand.

3.2. *Bt Brinjal*

In 2010, after GEAC approval, Bt brinjal faced a moratorium imposed by the Ministry of Environment, Forest and Climate Change (MoEFCC) citing "precautionary principle" concerns. Civil society protests, state government opposition, and lack of transparent biosafety data fueled the ban (Herring, 2015). This case marked a turning point where public skepticism outweighed scientific assessments, demonstrating the power of socio-political resistance.

3.3. GM Mustard

GM mustard (DMH-11), developed by Delhi University, was recommended for approval by GEAC in 2017 and 2022. However, its release remains suspended due to ongoing Supreme Court litigation and activist challenges about biodiversity and seed sovereignty (Narayanan, 2023). This case illustrates judicial activism and the deep entanglement of science with politics in India.

4. POLICY & REGULATORY ENVIRONMENT

India's biosafety governance involves overlapping agencies:

- RCGM (Review Committee on Genetic Manipulation) under DBT: Oversees early-stage laboratory research.
- GEAC (Genetic Engineering Appraisal Committee) under MoEFCC: Final approval authority for environmental release.
- MoEFCC (Ministry of Environment, Forest and Climate Change): Exercises political discretion, as seen in Bt brinjal's moratorium.
- DBT (Department of Biotechnology): Promotes biotech research but lacks decision-making authority.

Judicial interventions have complicated approvals. Public Interest Litigations (PILs) in the Supreme Court have stalled GM mustard and challenged biosafety protocols (Ramaswami, 2014). Internationally, India is a signatory to the Cartagena Protocol on Biosafety and the Convention on Biological Diversity (CBD), emphasizing precautionary approaches that influence domestic regulation.

5. CONCLUSION

The history of GM crops in India indicates that there has always been a tension between scientific proof and socio-political opposition: whereas Bt cotton returns are sometimes tangible and provide measurable benefits, the failure of Bt brinjal and GM indicate how precaution, mistrust, and opposition to legal legalization can impede expert judgment. In order to progress, India can enhance the biosafety infrastructure by conducting long-term transparent independent field trials; regulatory coherence by consolidating overlapping competences into a single empowered body; and further enhancing public engagement to promote communication and awareness to both the farmers and consumers. The adoption strategy should also be balanced (preferably preferring crop-specific approvals such as food and non-food crops) and long-term investment in indigenous biotechnology research, instead of learning as part of transparent and science-oriented models in countries such as Brazil and China, but with sensitivities to the biodiversity and culture of India. Finally, the reserved approach to biotechnology used in the country is indicative of democratic pluralism, yet it is pivotal to have a clearer sense of governance and evidence-based policymaking to use biotechnology to its fullest with considering ecological and social protection.

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