ISBN: 978-81-19149-69-8

6. Genetically Modified (GM) Crop in Indian Agriculture: A Brief Overview

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Abstract:

The advent of genetically modified (GM) crops has revolutionized the agricultural landscape by introducing novel traits and enhanced crop productivity, but introduction of genetically modified (GM) crops in Indian agriculture has sparked a contentious debate and ignited numerous controversies, reflecting the complex interplay between science, policy, economics, and societal concerns. The chapter begins by delving into the historical context of GM crops in India, highlighting the development and adoption of genetically modified organisms (GMOs) and the regulatory frameworks that govern their cultivation. It explores the scientific advancements that have led to the creation of GM crops, examining the potential benefits such as increased productivity, enhanced nutritional value, and resistance to pests and diseases. The chapter begins by elucidating the process of genetic modification and the techniques employed to introduce desirable traits into crop plants. It explores the various GM crop traits that have been developed, such as herbicide tolerance, insect resistance, disease resistance, and improved nutritional content, by different methods like CRISPR-Cas9, Agrobacterium mediated and Particle gun methods highlighting their significance in addressing global scenario & challenges, such as food security and sustainability. Different methodologies like gene flow, potential effects on non-target organisms and the development of herbicide-resistant weeds and insect pests are discussed here. It delves into studies examining the environmental consequences of GM crop cultivation, including both short-term and long-term effects, and presents a balanced analysis of the available scientific literature. The chapter explores the regulatory frameworks governing the cultivation and commercialization of GM crops in different regions of the India. It compares the approaches taken by various countries and international organizations to assess the risks and benefits associated with GM crops, providing insights into the factors influencing regulatory decision-making processes. The chapter concludes by summarizing the knowledge regarding the evaluation of GM crops in Indian agriculture. It emphasizes the importance of adopting a science-based approach in assessing the risks and benefits of these crops, promoting transparent and evidence-based decision-making, and fostering public dialogue to address the concerns and perceptions surrounding GM technology.

Keywords:

GM, GMOs, food security, sustainability, environment, genetic.

6.1 Introduction:

Genetically Modified Crops / Biotech crops are plants, the DNA of which has been modified using genetic engineering techniques, to resist pests and agents causing harm to plants and to improve the growth of these plants to assist in farmers efficiency. By 21st century the genetic engineering is one of the greatest achievements to human. This mechanism is allowed for specific control over the genetic changes introduced into an organism. Now a days, we can incorporate new genes for desired traits from one species into a completely unrelated species through genetic engineering, enhancing agricultural performance with profitability. The plants produced by the insertion of specific segments of foreign DNA sequence into its genome using transformation methods (such as Agrobacterium-mediated transformation or direct gene transfer method) are known as transgenic plants (Grifths *et al*., 2005). The inserted or transferred gene, also known as transgene, may receive from an unrelated plant, bacteria, virus, fungus, or an animal species (Figure 6.1).

Figure 6.1: Genetic Modification

The natural ability of Agrobacterium tumefaciens to stably insert Ti plasmid DNA (T-DNA) into host plant cell genome was discovered by Chilton *et al.*, 1977, consequently Ti plasmid was proposed as a vector to launch foreign genes into plant cells and along with it this study led the breakthrough related in appearance of the development of transgenic plants. India became familiar to Green Revolution in Wheat and Rice during 1970s which made our country self-sufficient in terms of food grains production. But the global scenario has totally changed significantly in 21st century due to climate change and increasing population pressure to meet the adequate feed. World hunger is on the rise again, to get rid of from these hunger and malnutrition by 2030 will be challenging and it will be achieved by sustainable agriculture and collective efforts by all the stakeholders (FAO, IFAD, UNICEF, WFP and WHO 2017). The conventional technologies continuing for over after year will not be able to meet the quality food and nutrition requirements. The advances in modern biology, specifically biotechnology and molecular biology may only get the achievement by offering many advantages when applied in combination with the traditional plant breeding techniques. The research based and technological assistance in these areas have been moved forward at a remarkable momentum during the last decade at the universal level. The under followings are the application and adoption with invention in very brief: -

- The first genetically engineered crop plant was tobacco, resistant to herbicides, reported in 1983 and first field trials were conducted in France and the US in 1986.
- In 1987 Marc Van Montagu and Jeff Schell was first to introduce insect resistant plants by incorporating genes that produced insecticidal proteins from *Bacillus thuringenesis* into tobacco.
- A virus resistance tobacco was introduced by People's Republic of China in 1992 which was first commercialised transgenic plants in Worldwide.
- In 1994 7th May Californian company Calgene attained approval to commercially release the Flavr Savr Tomato (CGN-89564-2), a tomato engineered to have a longer shelf life by decreasing pectin degradation where the regulating genes were Neomycin Phosphotransferase II, Polygalacturonase
- In 1995 Bt Potato was approved safe by the Environmental Protection Agency after having been approved by the FDA, making it the first pest resistant crop in United States. To resist against Colordo Potato Bettle the Bt potato was introduced by incorporating Cry3A delta-endotoxin from *B. thuringiensis* var. *tenebrionis*.
- By 2010, 67 countries had granted regulatory approval for importing of transgenic crops. Among them USA tops the list followed by Japan, Canada, Mexico, South Korea, Australia, the Philippines, New Zealand, the European Union, and Taiwan. Corn has the highest number of approved GM crops (65), followed by cotton (39), canola (15), potato and soybean (14 each).

Later on, several transgenic crops, such as canola with modified oil composition, Bt Potato, Bt maize, Bt cotton, bromoxynil herbicide-resistant cotton, and glyphosate-resistant soybeans, etc., received approval for commercialization (James 1997). Till to date, a total of 525 transgenic events in 32 crops have been commercialised (ISAAA database 2019). Among these, maize score the maximum number of events (238), followed by cotton (61), potato (49), Argentine canola (42), soybean (41), carnation (19) and others.

6.2 Why Genetically Modified Crops should be Cultivated?

In very short it provides more food, higher yield, insect resistant to crop, herbicide resistance, drought tolerance, protection crops from thrives in flooded areas. In broad aspect the specific reasons have been discussed for growing genetically modified crops:

By 2050, due to rapid population growth and dietary changes associated with economic growth 60 % more food will be needed. To meet future Global challenges which is corelated in terms of agricultural production, may have potential to feed the rapidly increasing global population by 2050. More than 25 % of greenhouse gas emissions by humans are caused by the agricultural machineries, forestry and livestock industries while deforestation, use of fertilizers, soil tillage and medicine from livestock animals (Brookes and Barfoot, 2020). Due to climate change by rising temperature day by day there is an increasing rate of pest and disease infestation but this problem can be solved by the resistant and tolerant varieties. Herbicide tolerant crops, disease resistant crops, insect resistant crops, drought tolerance tolerant crops, submerged resistant and salt resistant crops in the form of genetically modified crops having a contribution to provide stable supply of food. There is an increase in yield of 20% or more, compared to no GM crops with an annual yield growth effect equivalent to 24 million hectares of agricultural land worldwide. On average, genetically modified technology has increased crop yields by 21 percent. These increased yields are not due to higher genetic yield potential, but to more functional pest control and thus lower crop destruction. Subsequently, GM crops have reduced pesticide quantity by 37% and pesticide cost by 39%. Though the GM seeds are higher priced than non-GM seeds, but the additional seed costs are compensated through savings in chemical and mechanical pest control. Average surplus for GM-adopting farmers is 69% (Klumper and Qaim, 2014). The meta-regressions explain how different factors influence impact heterogeneity. Controlling for other factors, yield gains of insect resistant crops are almost 7 percentage points higher than those of Herbicide tolerant crops, after all yield gains of GM crops are 14 percentage points higher in developing countries than in developed countries (Klumper and Qaim, 2014). This meta-analysis confirms that the average agricultural and economic benefits of GM crops are large and significant, despite the heterogeneity of impacts. The impact is particularly dependent on the altered nature of crops and geographic regions. Yield increase and pesticide reduction are higher in IR crops than in HT crops.

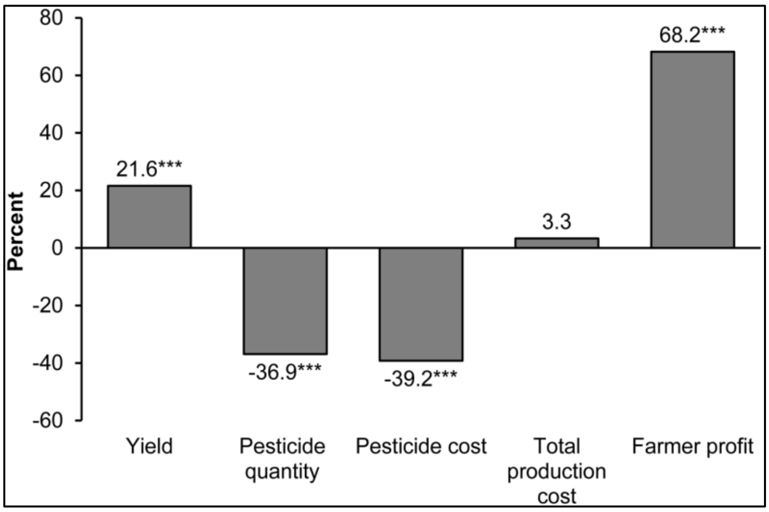


Figure 6.2: Impacts of GM crop adoption

Average percentage differences between GM and non-GM crops are shown. Results apply to all GM crops, including resistance to herbicides and insects. The number of observations depends on the outcome variable. output: 451; Number of pesticides: 121; Pesticide cost: 193; Total production cost: 115; Farmer's Profit: 136. *** indicates statistical significance at the 1% level. doi:10.1371/journal.pone.0111629.g002

The major increases in yields have occurred in developing countries, contributing to a safer and more stable food supply base in these countries. In South America, HT technology has helped farmers reduce tillage by shortening the time between planting and harvesting, allowing them to grow an additional soybean crop after wheat in the same growing season. With higher yields and less time and money spent on pest and weed control, farmers earn higher incomes. This has proved to be especially valuable for farmers in developing countries where, in 2018, an average 4.41 USD was received for each extra dollar invested in biotech crop seeds. The widespread use of genetically modified crop technology also changes the amount of land occupied by agriculture, allowing farmers to grow more without using up additional land. To keep global production levels at 2018 levels without biotech crops, farmers will need to plant an additional 12.3 million hectares of soybean, 8.1 million hectares of maize, 3.1 million hectares of cotton and 700,000 hectares of rapeseed. It is equal to the combined agricultural area of the Philippines and Vietnam.

The main impact of these techniques on farm income has been to reduce levels of harmful pests and consequently increase crop yields. (Table.1). Yield increases were greatest in developing countries where traditional pest management practices have proven least effective (e.g., where expansion and expansion services are poorly developed or lack of access to funds to finance the use of plant protection equipment and products), with any cost savings associated with reduced insecticide use being mostly found in developed countries. These effects can be seen in the level of increase in farm income resulting from the introduction of these technologies.

Table 6.1: Farm Income Calculations of 2018 on cultivating of GM Insect resistant Corn (targeting corn boring pests)

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	27,125	+7	10.47	137	+23.52	+21.58	+78.54	+2,363,238	+21,586
Canada	1,232	+7	9.16	150	+26.0	+23.54	+72.94	+89,897	+790
Argentina	5,114	+5.5	7.95	151	+19.9	+19.9	+46.27	+236,667	+2,237
Philippines	593	+18	3.0	266	+38.0	+25.62	+119.0	+70,849	+324
South Africa	1,528	+10.6	4.48	174	+11.33	0.00	+82.43	+125,963	+725
Spain	115	+12.6	10.76	214	+43.09	+35.53	+219.24	+25,267	+156
Uruguay	107	+5.5	7.24	226	+19.86	+19.86	+70.26	+7,067	+40
Honduras	32	+24	3.38	310	+100.0	+100.0	+151.46	+14,851	+26
Portugal	6	+12.5	7.85	203	+44.27	+44.27	+155.30	+914	+6
Brazil	13,949	+11.1	5.03	128	+57.18	+42.10	+29.67	+413,878	+7,792
Colombia	70	+16	5.20	244	+47.60	+5.80	+196.67	+13,835	+58
Paraguay	322	+5.5	5.46	151	+16.79	+16.79	+28.61	+9,226	+97
Vietnam	49	+7.2	4.65	235	+37.94	+27.29	+105.81	+5,185	+16

(Source: Graham Brookes & Peter Barfoot (2020) GM crop technology use 1996-2018: Farm income and production impacts)

Without GM crops, 24 million hectares of new land would be needed to sustain production in 2018. By reducing tractor fuel consumption and reducing soil carbon emissions via no tillage cultivation, carbon emissions is reduced to 23 billion kg (equivalent to 15.27 million cars) in 2018. Inhibition of soil erosion due to no-tillage and removal of organic matter into rivers. The Water Efficient Maize for Africa (WEMA) project is a collaborative effort to develop maize that combines drought and pest resistance for smallholder farmers in sub-Saharan Africa by the public and private sectors for conservation of water resources. GM apples and potatoes, which are resistant to browning caused by scratches or physical impact, enable the elimination of unnecessary disposal due to poor appearance which in turns reduce the amount of food waste.

It is said that more than 2 billion people worldwide suffer from hidden hunger (micronutrient deficiencies that do not make you feel hungry). In developing countries in Africa and Asia, between 250,000 and 500,000 children each year lose their sight due to vitamin A deficiency, half of whom die within 6 months of losing their sight. In order to improve vitamin A deficiency in such poverty-stricken areas through a staple diet, golden rice, which is a GM rice (Golden Rice) that produces beta-carotene, a precursor of vitamin A, is under development. It is available free of charge in developing countries in need. Golden Rice is also the subject of campaigns against genetically modified crops. In 2016, more than 100 Nobel laureates were concerned about this situation and jointly issued a letter calling for an "immediate end to the campaign against GM crops, especially golden rice." Also, the contributions of GM crops include fewer environmental resources (such as water and fertilizer), less pesticide use, more food at a lower price, and longer shelf life.

6.3 Methods Genetic Modification Techniques:

There are two main techniques for genetic manipulations: Genetic and Nongenetic engineering; however, there is not a disjunction between genetic and nongenetic engineering as some mechanisms are regular to both techniques.

Methods for genetic modification	Nongenetic Engineering	• Simple selection (the selection of plants for continued propagation according to a desired phenotype)
		• Embryo rescue (the rescue of plants from hybrid embryos that cannot survive in vivo)
		• Crossing (Hybrids are obtained by crossing sexually compatible individuals of different breeds.)
		• Somatic hybridization (obtaining new hybrids through the in vitro fusion of protoplast derived from different plants)
		• Somaclonal variation (Genetic diversity found in in-vitro progeny cell/tissue culture)

		• Mutation breeding (Use of chemical or physical mutagens to produce new plant varieties)
		• Cell selection (Isolation and cultivation of cells selected for the desired phenotype that can be used to regenerate whole plants)
	Genetic Engineering	• Targeted manipulation of genetic material (e.g., cloning, viral vectors, microprojectile bombardment, electroporation or microinjection)
		• Off-target manipulation of genetic material (random DNA mutations due to chemical or physical mutations).

6.3.1 Non-Genetic Engineering Methods:

The oldest method of engineering comprises of selecting individual seed populations that adjoin the desirable traits (e.g., special phenotype or physical characteristics). This technique is still employed but right now it is based on molecular analysis that identifies certain selection markers (mainly those that address resistance to plant diseases) and thus permitting a more rapid selection of species with essentially important agronomic traits.

Crossing allows researchers to produce hybrids from two sexually congenial plants; however, this is a strenuous process as recombination is random and requires a large number of hybrid intermediates to be brought out before those with the desired traits are obtained.

Embryo rescue technique (or embryo culture) is based on the insertion of the embryo in a specific culture medium before seed abortion can occur and is applied to breed parental lines with incompatible genomes (Mahgoub, 2015).

Being a nonsexual genetic method, Somatic hybridization is based on the fusion of protoplasts acquired from different plants. The removal of cellular walls through degradation of polysaccharides by cellulase, hemicellulase and pectinase and the pooling of protoplasts in the presence of a chemical or electrical fusogen results in the assembly of a heterokaryon (Mahgoub, 2015) which has genetic material from both plant sources.

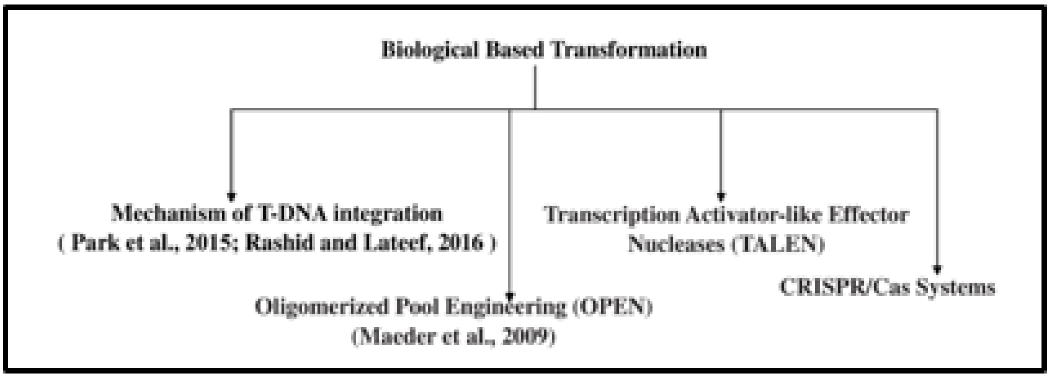
Mutagenesis is induced by chemicals and physical factors and is used to induce random moderation in the genomes of plants. The randomness and non-reproducibility of these mutations make the methods not useful for food.

Ethyl Methane Sulfonate, Calcium Phosphate (Chowdhury *et al*., 2004), and Methyl Methane Sulfonate (MMS), Diethyl Sulfate, and Nitrosoguanidine are commonly used chemicals as mutagenic material; where physical factors like electroporation, biolistics, vacuum infiltration, silicon carbide whiskers, ionizing radiation, andshock wave mediated transformation are commonly used (Rivera *et al*., 2014).

6.3.2 Genetic Engineering Methods:

Genetic engineering for crop modification have been further more classified into two groups: Biological based and non-biological based.

A. Biological Based Transformation:



In biological-based transformation methods the plasmids used are circular extrachromosomal double-stranded molecules of DNA found in yeast, bacteria and some eukaryotic cells. These mentioned molecules are not essential for host survival but they can confer them some dominance in certain environmental circumstances or over other organisms from the same ecological niche (Actis *et al.*, 1999).

In the technique of T-DNA, it launches into the host as single stranded DNA (*Park et al.*, 2015; Rashid and Lateef, 2016). The integration system of T-DNA is activated by phenolic and sugar molecules that induce virulence proteins in the plasmid in consequence leading T-DNA into the host cell by VirD2 proteins via the Agrobacterium type IV secretion system formed by the VirB1-11 and VirD4 proteins. The VirD2 is an endonuclease that cut T-DNA from plasmids and remains connected at the 5' end of the T-strand. The nuclear targeting of the VirD2/T-strand complex is mediated by importing α proteins which permits the passage of the complex into the nucleoplasm through nuclear pores. Another protein involved in nuclear targeting of the T chain is VirE2, which also protects the T chain from nuclear degradation in the host cell (Gelvin, 2012; Rashid and Lateef, 2016; Tzfira and Citovsky, 2006; Ziemienowicz, 2014). The T-strand is proteolytically shed from the nucleus and converted to a double-stranded form by DNA repair mechanisms. The resultant intermediary form (ds T-DNA) is recognized as a broken DNA fragment and integrated intothe host (Park *et al*., 2015; Rashid and Lateef, 2016; Tzfira and Citovsky, 2006).

The Oligomerized pool engineering (OPEN) is further classified in ZFN and ZFP mechanism. Zinc finger proteins (ZFP, ZFN) are a group of transcription factors, with Cys_2-His_2 zinc fingerdomain, the most common DNA-binding domains in the plant genome. ZFP consists of a cleavage domain and a binding domain derived from Fok (IIS restriction enzyme). The DNA molecule is wrapped around with the binding domain of a ZFP in the presence of a zinc atom, each finger binding with 3–4 base pairs (bp). ZFP forms a compact ββα structure with the DNA molecule targeting a site of 9 base pair (Maeder and Gersbach, 2016). To enable DNA double-strand breaks, two ZFP binding sites located in reversed orientations on the top and bottom strands of the DNA substrate dimerize, facilitating the activity of the nuclease domain. Since each ZFP from the dimerized complex requires two copies of 9 base pairs sequences in a tail-to-tail orientation, the specific recognition site which must have 18 base pairs to induce cleavage of the DNA molecule (Durai *et al*., 2005). Transcription activator-like effector nucleases (TALEN) are formed of a DNA-binding domain specific to TALE proteins (original from *Xanthomonas*) and a DNA-cleavage domain. The formation of dimers is essential for the induction of double-strand DNA breaks. The DNA-binding domain is constructed of a tandem of 33–35 aminoacids, followed by a single repeat of 20 amino acids. The amino acids in positions 12 and 13 of each repeat are responsible for recognizing and binding a single nucleotide base. Now a days several procedures to engineer TALEN arrays are available.

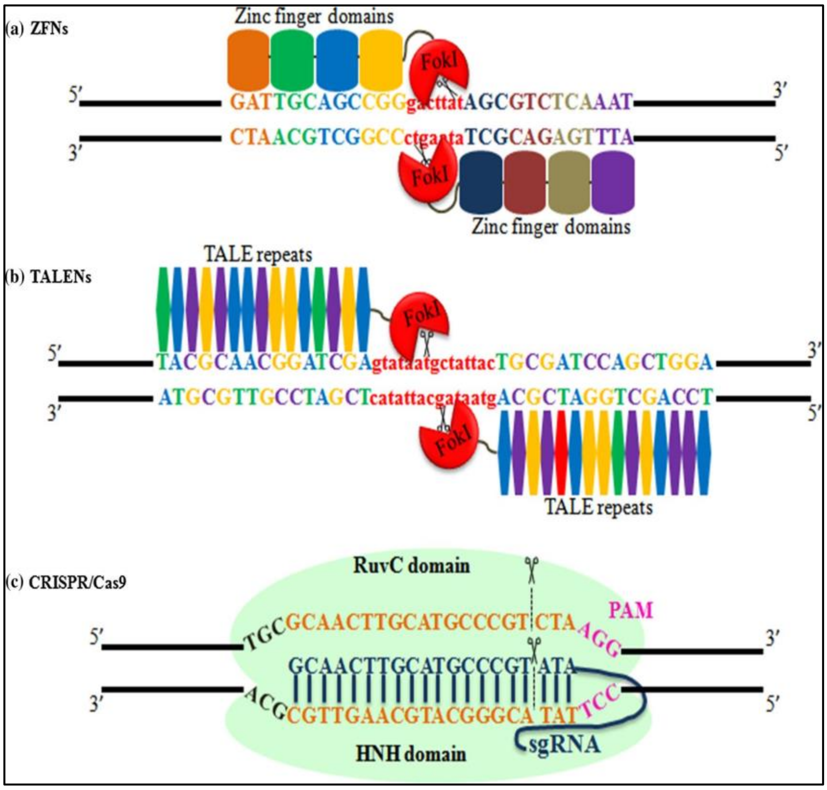
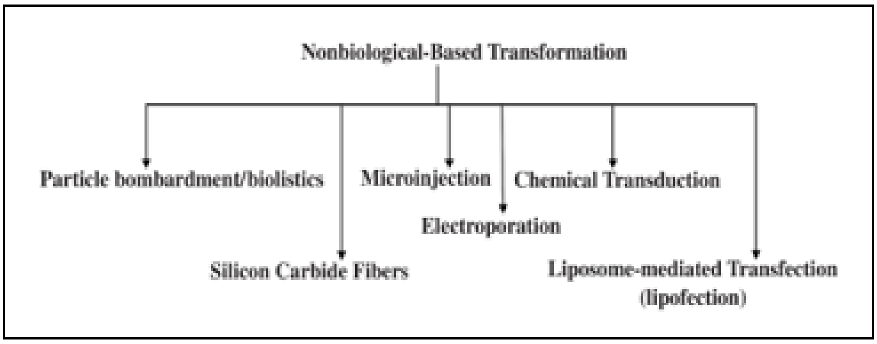


Figure 6.3: Biological based transformation techniques

CRISPR/Cas 9 technology is the most effective, efficient and accurate genome editing method in all living cells and has many applications. Guide RNA (gRNA) and CRISPR-associated (Cas-9) proteins are two important components of the CRISPR/Cas-9 system. The CRISPR/Cas-9 genome editing mechanism involves three steps: recognition, cleavage, and repair. The designed sgRNA recognizes the target sequence of the gene of interest through complementary base pairing. While the Cas-9 nuclease makes a double-strand break at site 3 of the base pair upstream of the motif adjacent to the protospacer, the double-strand break is repaired by non-homologous end-joining or cell homology-directed repair mechanisms. The CRISPR/Cas-9 genome editing tool has many applications in many fields including medicine, agriculture and biotechnology. In agriculture, it helped in designing of newly introduced GM crops to improve their nutritional value, resistance and tolerance mechanism.

B. Nonbiological-Based Transformation:

Nonbiological-based methods of plant transformation includes:



Most commonly nonbiological-based methods used are discussed below:

- Agrobacterium mediated gene transfer method:

Agrobacterium, a soil bacterium, has the ability to infect some plants and insert a DNA region from its own plasmid called T-DNA into the plant's genome. The Agrobacterium method uses this property to integrate the gene of interest along with the T-DNA into the plant genome.

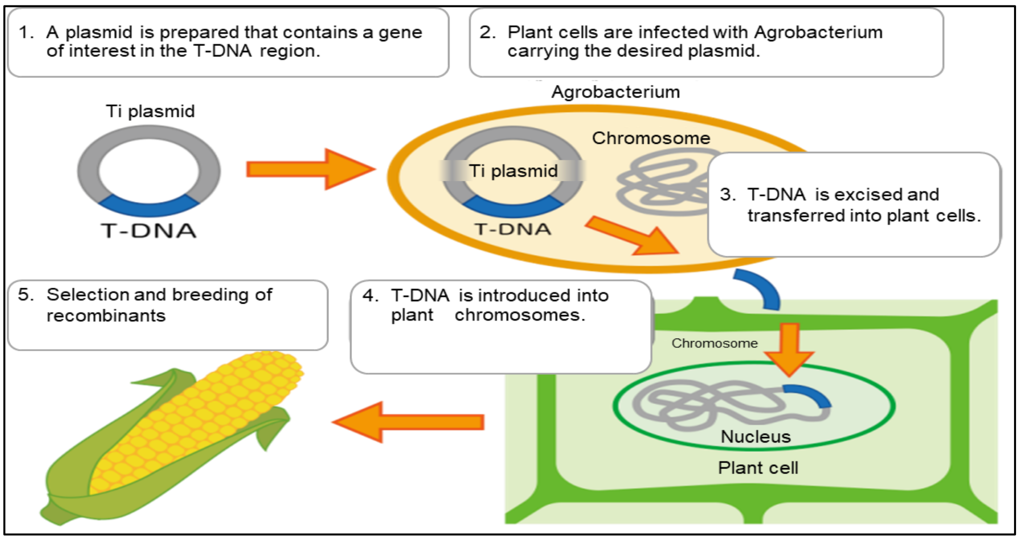


Figure 6.4: Agrobacterium mediated gene transfer technique

- **Particle Gun method:**

This is a method of incorporating the gene of interest into the plant genome by physically introducing the gene of interest into plant cells by coating the gene of interest on metal particles.

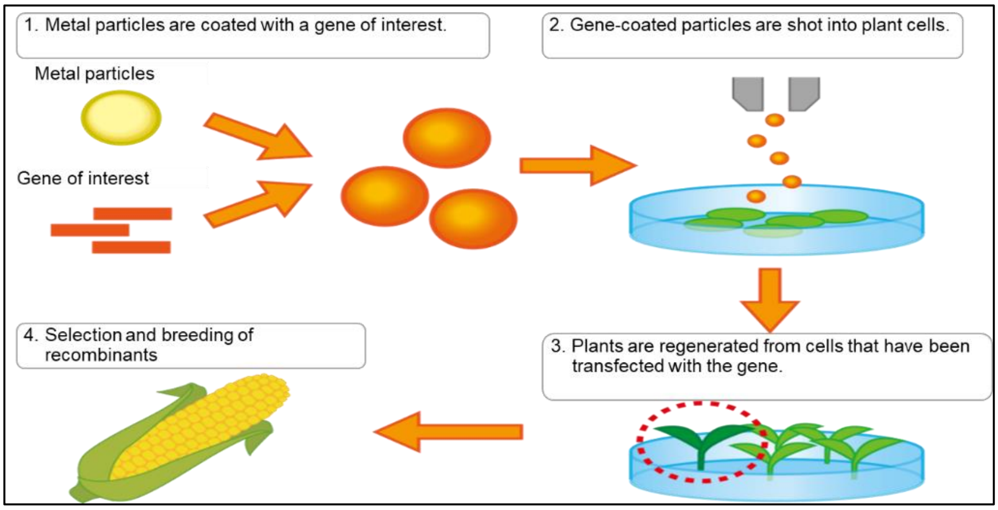
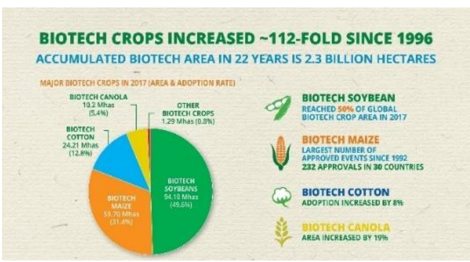


Figure 6.5: Particle Bombardment gene transfer technique

6.4 Global Scenario of Genetically Modified Crops:

Through the entire world 67 countries adopted biotech crops since 1996 where 24 countries are the planting and importing, 43 are only importing biotech crops in Africa, Asia & the Pacific, Europe, latin America and North America. The Biotech crops increased in 112-fold since 1996. Among all crops biotech soyabean, biotech maize, biotech cotton and biotech canola accounts for major crops in terms of adaption in 2017.



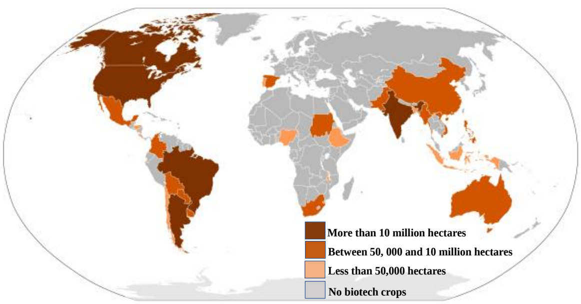


Figure 6.6: & Figure 6.7: **Area under GM crop distribution**

More than 189.18 million hectares biotech crops are being cultivated where 17 million farmers are engaged. In recent times it is the fastest adopted crop technology according to the International Service for the Acquisition of Agri-biotech Applications report. Among of

10 million hectares of Genetically modified crops cultivation USA, Brazil, Argentina, India, Canada, Paraguya are major countries. The fig shows the presents status of area distribution under GM crops.

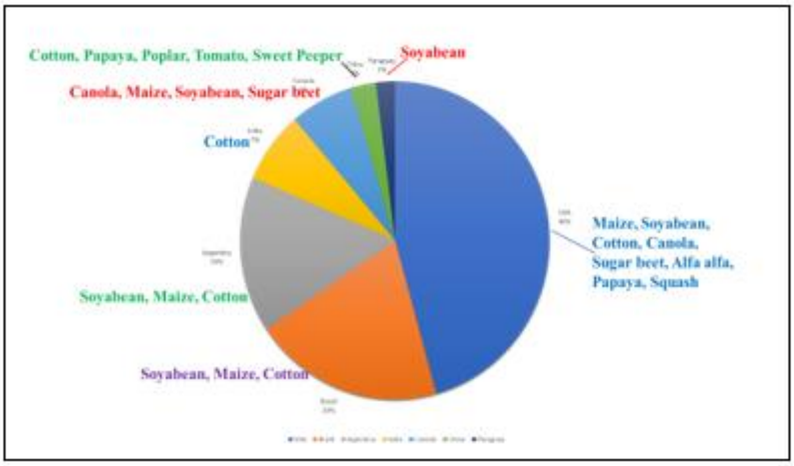


Figure 6.8: GM Crop Production Percentage

The USA consists of huge production of Maize, Soyabean, Cotton, Canola etc and claims the 1st rank in terms of production as well as number of crops cultivated. It accounts of 46 % of entire production of GM crops. Brazil accounts for 20 %, followed by Argentina (16%), India (7%), Canada (6%), China & Paraguya.

6.5 Genetically Modified Crops of World and India:

Table 6.2: A total number of 32 genetically modified crops have been approved for cultivation through the entire world. Those crops are enlisted below:

Sr. No	Name	Sr. No.	Name	Sr. No.	Name
1	Corn	12	Wheat	23	Safflower
2	Potato	13	Rice	24	Pigeon pea
3	Sugar Beet	14	Squash	25	Chicory
4	Polish canola	15	Pineapple	26	Cowpea
5	Maize	16	Sugarcane	27	Creeping bentgrass
6	Canola	17	Tomato	28	Eucalyptus
7	Egg Plant	18	Tobacco	29	Flax
8	Poplar	19	Rose	30	Melon
9	Carnation	20	Papaya	31	Plum
10	Soya Bean	21	Sweet Peeper	32	Bean
11	Alfa Alfa	22	Apple		

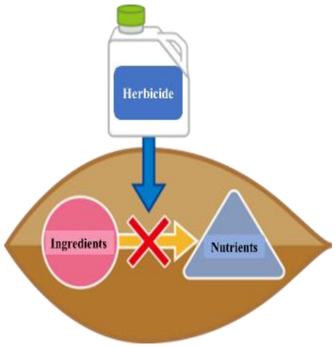
Table 6.3: Crops that are in various stages of of research, field trials and financial issue in India are enlisted below:

Sl No.	Name	Sl No.	Name	Sl No.	Name
1	Bt Brinjal	6	Protato	10	Maize
2	GM Mustard	7	Rice	11	Groundnut
3	Okra	8	Pigeon pea	12	Sugarcane
4	Chickpea	9	Castor	14	Cauliflower
5	Sorghum	10	Wheat		

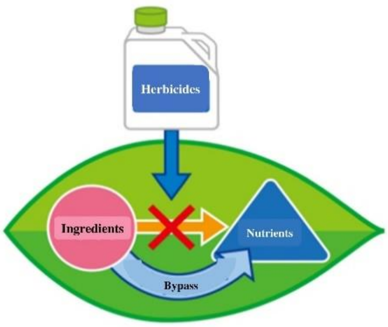
6.5.1 Herbicide Tolerant Crops:

A. Outline: Herbicide-tolerant crops are crops made by using genetically modified technology so that they do not wither even when a specific herbicide is sprayed. The use of certain herbicides during cultivation can kill weeds without damaging the crop, thereby reducing the strain on farming.

B. Typical Mechanism: Usually, when herbicides are applied to weeds, they become unable to make nutrients and consequently wither. Also, the accumulated components can be toxic to growth.



In contrast, with herbicide-tolerant crops, such crops can grow by degrading the herbicides or creating a synthesis path that is not hindered by the herbicides.



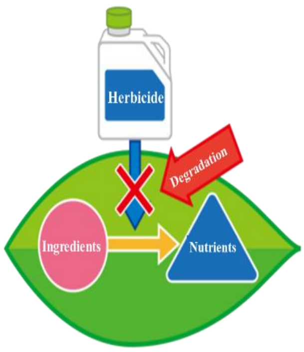


Table 6.4: Herbicide Tolerant GM Crop Varieties:

Name	Use	Variety
Alfalfa	Animal feed	438RR, MON-ØØ163-7
Canola	Cooking oil, Margarine, Emulsifiers in packaged foods	Hyola 525RT, Bayer 3000TR, Hyola 404RR, Pioneer45Y88CL, Hyola 559TT
Cotton	Fibre, Cotton Seed oil Animal feed	CEMB-1317, CEMB-1330, DD-Ø1951A-7
Maize	Animal feed, high-fructose corn syrup, corn starch	MON 802, MON 832, MON 88017, 3751IR, DP-ØØ4114-3,
Soybean	Animal feed, Soybean oil	LL GT27, GTS 40-3-2,
Sugar Beet	Food	SY-GTSB77-8, ACS-BVØØ1-3

6.5.2 Insect-Resistant Crops:

Pest control using insecticides has additional disadvantages in that it requires repeated spraying according to the time at which pests appear and is ineffective against pests invading plants. Insect-resistant crops that produce “Bt proteins,” which have an insecticidal activity, allow farmers to reduce the time and effort of pesticide application, as well as the ammount of pesticides used.

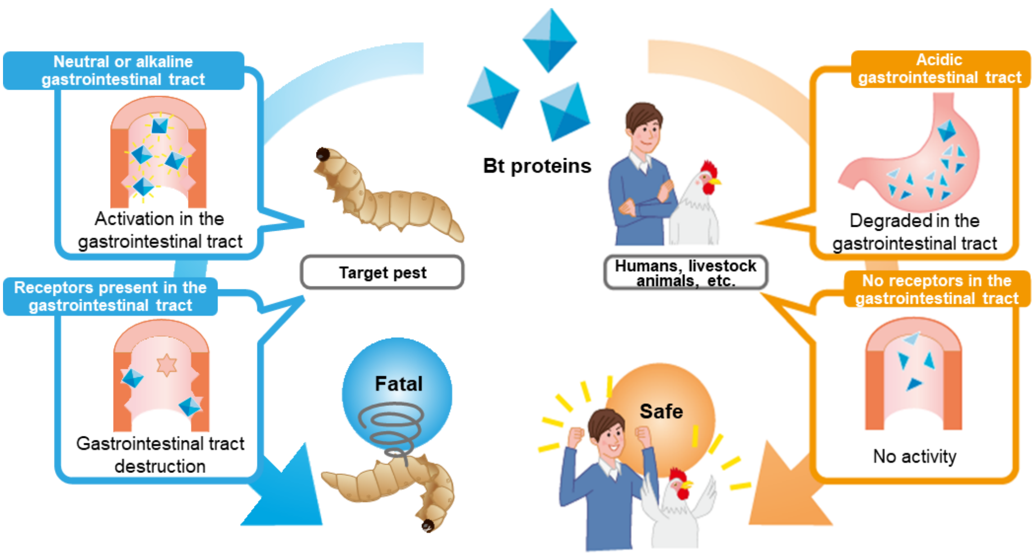


Figure 6.9: Insect Resistant Mechanism

The Bt protein produced by soil microbes (*Bacillus thuringiensis*) acts specifically on target pests. It has been used safely as a bioinsecticide for decades and is approved for use in organic agriculture.

Damage caused by insidious pests

(Left) Non-GM, (Central) Insect-resistant GM, (Right) Non-GM sprayed with pesticides

Figure 6.10 & Figure 6.11: Different Infesting Symptoms by the Pests

Table 6.5: Insect resistant GM crop varieties:

Name	Use	Variety
Cotton	Fiber, Cotton seed oil, Animal feed	MECH-184, MECH-12, MECH-162, CCRI41, CCRI45
Egg Plant	Food	Bt Uttara, Bt Kajla, Bt Nayantara, Bt ISD006
Maize	Animal feed, high-fructose corn syrup, corn starch	MON863, MON 809, SYN-IR162-4, SYN-IR6O4-5, DP-ØØ4114-3
Potato	Food	New Leaf

6.5.3 Disease resistant crop:

Crop damage due to diseases caused by bacteria and viruses are always a source of distress to farmers. The disease can spread so quickly in crop areas that the development of pesticide- and disease-resistant varieties can't keep up, putting many farmers out of business. Rainbow papaya, a GM papaya developed in Hawaii, which is resistant to the papaya ringspot virus.

In the early 1990s, papaya ring spot virus spread rapidly through the Hawaiian papaya. Entire trees eventually wilt and die when infected with this virus. The disease has significantly reduced papaya production in Hawaii.

In 1997, researchers at the University of Hawaii and Cornell University developed a papaya variety that is resistant to ringed spot virus to save Hawaiian papaya production from extinction.

Developed in 1998 when commercial cultivation of papaya was allowed, papaya was provided free of charge to papaya farmers, and papaya production was restored to the original level. In 2011, GM papaya was approved for import in Japan after its safety was confirmed. Now popular with many as rainbow papaya.

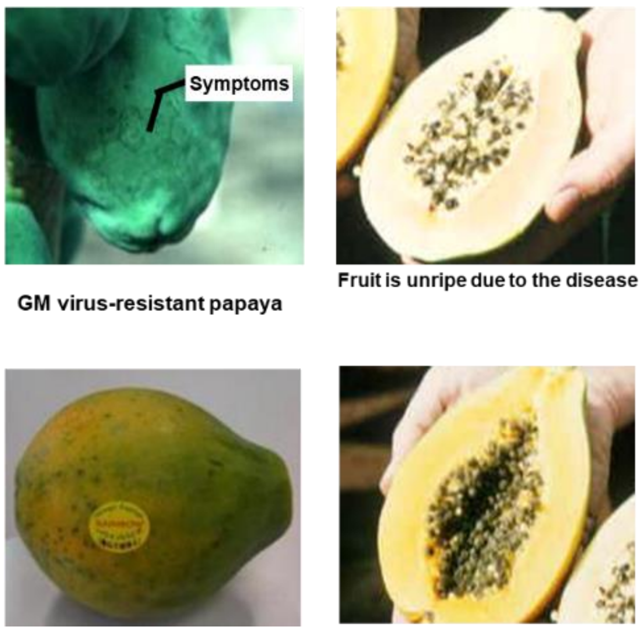


Figure 6.12: Genetically Modified Papaya

Table 6.6 List of Disease resistant GM crop Varieties:

Name	Use	Variety
Papya	Food	U H Rainbow, Sun Up, Rainbow
Potato	Food	Innate Gen 2, Russet Burbank, Ranger Russet, Atlantic
Squash	Food	Yellow Straightneck, Yellow Crookneck and Green Zucchini

6.6 Regulatory Bodies in India:

India signed the Cartagena Protocol on Biosafety and established a Biosafety Clearinghouse. It details biosafety rules for GMOs and proposes biosafety requirements for GM crop research and their role in commercialization and deregulation processes. The Department of Biotechnology (DBT) under the Ministry of Science and Technology was established to comply with biotechnology safety regulations and conduct biotechnology research in laboratories. Regulation of genetically modified organisms and their products should be based on the Environmental Protection Act 1986 (EPA 1986). A step-by-step regulatory framework for the assessment and biosecurity of GM crops is operated by six competent authorities under the auspices of MoEF&CC and the Department of Biotechnology (DBT), Ministry of Science and Technology, Government of India. The authorities are : The Recombinant DNA Advisory Committee (RDAC), The Review Committee on Genetic Manipulation (RCGM), The Genetic Engineering Appraisal Committee (GEAC), Institutional Bio-safety Committees (IBSC), State Biotechnology Coordination Committees (SBCC) and District Level Committees (DLC).

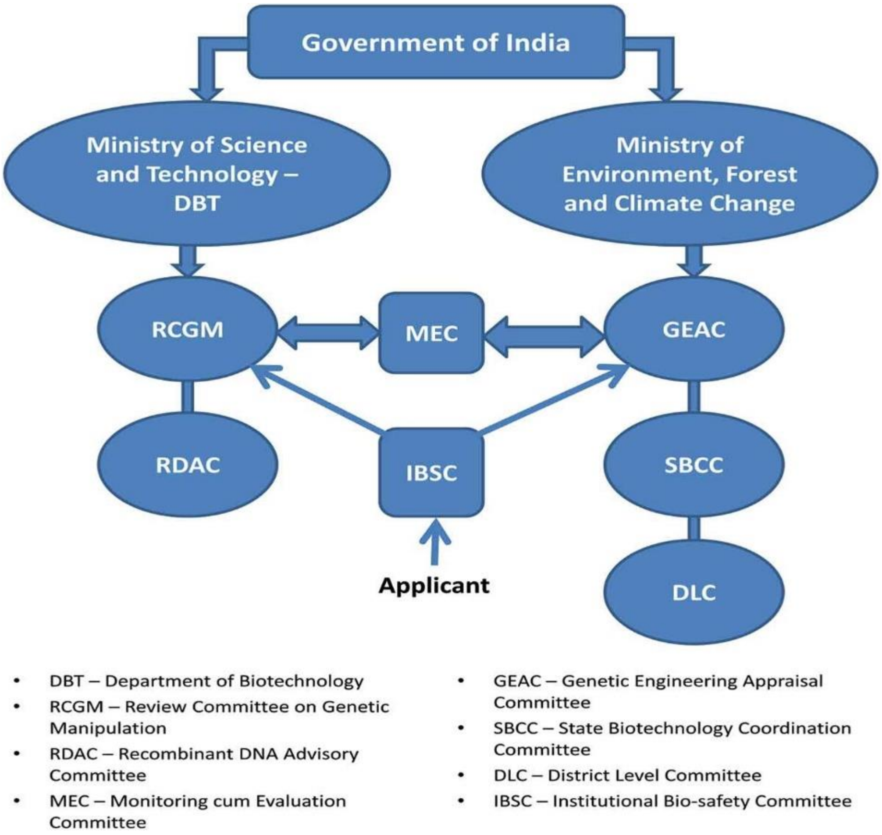


Figure 6.13: Framework of Regulatory Bodies

6.7 Issues and Controversy in India:

The Genetic Engineering Approval Committee (GEAC) cleared Bt brinjal for commercialization in October 2009 but some allegation raised by some farmers, anti-GM activists and scientists, the Government of India officially announced moratorium on 9 February 2010 and then Environment & Forest Minister Mr. Jairam Ramesh mentioned that there is no overriding extremity to release Bt brinjal in India and also recapitulated that the government had only imposed a moratorium on the release of transgenic brinjal hybrid, and not a permanent ban (MoEF 2010).

On 9 August 2012, the Standing Committee on Agriculture of the Lok Sabha Parliament concluded that "GM crops are not the right solution for our country". This committee also emphasized that Bt cotton has not improved the socio-economic condition of cotton farmers in India but further deteriorated especially in the rainfed farming areas of the country after consulting various stakeholders across India.

According to some scientists, there is no urgent need to commercialize GM crops in India as there is still no clear evidence that GM crops can actually increase yields. The evolution process, potential benefits and deregulation of Bt Brinjal in India remain the most controversial issues.

GEAC on July 18, 2014 has given approval for limited experimental field trials of GM Rice, Rrinjal, Mustard, Cotton and Chickpea for the sole purpose of generating biosafety data (The Hindu 2014)

GEAC has recommended the commercial cultivation of GM mustard for permitting to the Minister of Environment (Indian Express 2017), but a final decision has not yet been made. Though GM field testing are allowed for trials of few GM crops but several State Governments are still not ready to embrace this technology (Kumar *et al*.,2015).

On October 2018 GEAC meeting for GM organism recommended the "environmental release" of the transgenic mustard hybrid DMH-11, developed by the Centre for Genetic Manipulation of Crop Plants at Delhi University but the Swadeshi Jagaran Manch opposed to its release. GM mustard is dangerous and Ashwani Mahajan, national organizer of Swadeshi Jagran Manch, said it is not Swadeshi at all. As reported by the Supreme Court (November 30, 2022), irreversible environmental pollution with unknown consequences can occur after crops are released.

Table 6.7: Recently Approved Genetically Modified Crop varieties through the Entire World:

March 3, 2023	Brazil approved the commercial cultivation of HB4 wheat.
October 18, 2022	The Philippines approved the eggplant event EE-1 for cultivation
October 4, 2022	The United States approved the MON94100 canola event for food and feed.
July 18, 2022	Nigeria approved the HB4 wheat event for food and feed.
July 7, 2022	The United States approved food and feed corn event MON87429.
June 30, 2022	Ghana approved AAT709A Eastern Cultivation Activities for Food, Feed and Cultivation.
June 22, 2022	The USA approved the wheat event HB4 for food and feed.
May 31, 2022	Turkey approved the maize event MON87427 for feed.
May 6, 2022	Australia and New Zealand approved HB4 wheat for food and feed use.
March 24, 2022	The USA approved the canola event NS-B5ØØ27-4 for food and feed.
March 24, 2022	The United States approved the LFLFLFK canola event for food and feed.
March 9, 2022	The US allowed the cultivation of GMB151 soybeans.
February 1, 2022	Colombia approved the wheat event HB4 for food and feed.
November 11, 2021	Brazil approved the wheat event HB4 for food and feed.
October 21, 2021	The United States approved the DBN9858 corn event for food and feed.

September 21, 2021	The United States approved the planting of PY203 corn.
September 16, 2021	Australia sanctioned the MS11 × RF3 and MS11 × RF3 × MON 88302 canola events.
August 23, 2021	The United States approved Gen2-Z6 potato production for food and feed production.
August 17, 2021	The United States approved event DP202216 corn for food and feed.
August 5, 2021	The Philippines approved MON87429 maize for food, feed and processing.

6.8 Some Constraints of Genetically modified crops:

- **Allergic Reactions:** A study by the *New England Journal of Medicine* in 1996, showed that when a gene from a Brazil nut was engineered into soybeans, people allergic to nuts responded strongly to the modified product.
- **Toxicity:** GE foods are inherently unstable. Each insertion of a novel gene, and the accompanying “cassette” of promoters, antibiotic marker systems and vectors, is random. GM food manufacturers do not know where gene "cassettes" are inserted into food, nor are they sufficiently aware of the genetic/chemical makeup of food to establish a "safe" location for such insertion. As a result, each gene insertion into a food amount to playing food safety “roulette’’
- **Immune Suppression:** A study by Dr. Arpad Pusztai and Stanley W.B. Ewen in 1999 under a grant from the Scottish government, showed that the rats consuming genetically altered (B.t) potatoes showed significant detrimental effects on organ development, body metabolism, and immune function.
- **Loss of Nutrition:** In 1992, the FDA's Division of Food Chemistry and Food Contamination Technologies and Chemistry investigated the problem of nutrient loss in genetically modified foods. Scientists involved warned the agency that genetic engineering of foods in particular could lead to "undesirable changes in nutritional levels" of such foods.

6.9 Conclusion:

The wider adaptability of GM crops shows significant resistant to disease, insect, herbicide. Subsequently increased the nutritional value of foods like Golden rice to fight against hidden hunger, shelf life of crops, improved ornamental traits by genetic modification. But India still far away in adapting of GM crops.

There is not such significant evidence which can prove that GM crops are dangerous and are not ‘’Swadeshi’’. Although there is controversy, lack of knowledge to farmers & NGOs, legal issues related to GMO with Govt. body but Scientist, Research organisation, Institution should come forward for the future prospects.

It is technically true that India lacks basic infrastructure and strict guidelines for GM crop research and risk assessment, but given India's urgent needs, the country cannot stop this program.

Although portals such as GEAC, Indian GMO Research Information System (IGMORIS) and Biosafety Clearing House play a role in biosafety assessment and regulation of GM crops, there is an urgent need to establish a single pane of glass database system and online portal for assessment., the control, regulation and approval of GM crops.

The portal also includes a list of publications related to specific GM crop development, so anyone interested in GM crop development activities can get all the details along with the current status in one place.

6.10 References:

1. Actis, L. A., Tolmasky, M. E., & Crosa, J. H. (1999). Bacterial plasmids: replication of extrachromosomal genetic elements encoding resistance to antimicrobial compounds. *Frontiers in Bioscience-Landmark*, **4(4):** 43-62.
2. Brookes, G., & Barfoot, P. (2020). Environmental impacts of genetically modified (GM) crop use 1996–2018: impacts on pesticide use and carbon emissions. *GM Crops & Food*, **11(4)**: 215-241.
3. Brookes, G., & Barfoot, P. (2020). GM crop technology use 1996-2018: farm income and production impacts. *GM Crops & Food*, **11(4):** 242-261.
4. Choudhary, B., Gheysen, G., Buysse, J., van der Meer, P., & Burssens, S. (2014). Regulatory options for genetically modified crops in India. *Plant biotechnology journal*, **12(2):** 135-146.
5. Chowdhury, E. H., Kunou, M., Nagaoka, M., Kundu, A. K., Hoshiba, T., & Akaike, T. (2004). High-efficiency gene delivery for expression in mammalian cells by nanoprecipitates of Ca–Mg phosphate. *Gene*, **341:** 77-82.
6. Coombs, J. J., Douches, D. S., Li, W., Grafius, E. J., & Pett, W. L. (2002). Combining engineered (Bt-cry3A) and natural resistance mechanisms in potato for control of Colorado potato beetle. *Journal of the American Society for Horticultural Science*, **127(1):** 62-68.
7. Durai, S., Mani, M., Kandavelou, K., Wu, J., Porteus, M. H., & Chandrasegaran, S. (2005). Zinc finger nucleases: custom-designed molecular scissors for genome engineering of plant and mammalian cells. *Nucleic acids research*, **33(18):** 5978-5990.
8. FAO. (2014). Building a common vision for sustainable food and agriculture: principles and approaches.
9. Fernandez-Cornejo, J., Wechsler, S., Livingston, M., & Mitchell, L. (2014). Genetically engineered crops in the United States. *USDA-ERS Economic Research Report*, (162).
10. Gelvin, S. B. (2012). Traversing the cell: Agrobacterium T-DNA's journey to the host genome. *Frontiers in plant science*, **3**: 52.
11. https://agritech.tnau.ac.in/bio-tech/biotech_btcotton_env.html
12. https://cban.ca/gmos/products/on-the-market/squash/
13. https://naldc.nal.usda.gov/download/33613/pdf
14. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/nph-1.pdf
15. https://www.isaaa.org/gmapprovaldatabase/advsearch/default.asp?CropID=7&TraitTypeID=Any&DeveloperID=Any&CountryID=Any&ApprovalTypeID=3
16. https://www.isaaa.org/gmapprovaldatabase/default.asp
17. https://www.isaaa.org/gmapprovaldatabase/default.asphttps://www.agric.wa.gov.au
18. https://www.isaaa.org/purchasepublications/itemdescription.asp?ItemType=ECOPY&Control=IB055-2019-ECOPY

19. https://www.isaaa.org/resources/imagegallery/default.asp
20. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4574545/
21. https://www.supportprecisionagriculture.org/nobel-laureate-gmo-letter_rjr.html
22. https://www.swadeshionline.in/news/gm-mustard-crop-s-release-would-irreversibly-damage-the-environment-sc-told
23. https://www.swadeshionline.in/news/gm-mustard-crop-s-release-would-irreversibly-damage-the-environment-sc-told
24. https://www.thehindu.com/news/national/gm-mustard-not-swadeshi-extremely-dangerous-rss-affiliate-to-union-minister/article66065985.ece
25. https://www.thehindu.com/news/national/gm-mustard-not-swadeshi-extremely-dangerous-rss-affiliate-to-union-minister/article66065985.ece
26. Jayaraman, K. S., Fox, J. L., Jia, H., & Orellana, C. (2005). Indian Bt gene monoculture, potential time bomb. *Nature Biotechnology*, **23(2):** 158-159.
27. Klümper, W., & Qaim, M. (2014). A meta-analysis of the impacts of genetically modified crops. *PloS one*, *9*(11), e111629.
28. Knezevic, N., Dugum, J., & Frece, J. (2013). The status and prospects for genetically modified food in Europe and Croatia. *Journal of Central European Agriculture*, **14(1):** 250-260.
29. Kumar, S. (2015). India eases stance on GM crop trials. *Nature*, **521(7551):** 138-139.
30. Kumar, S., & Kumar, A. (2015). Role of genetic engineering in agriculture. *Plant Archives*, **15(1):** 1-6.
31. Latif, A., Rao, A. Q., Khan, M. A. U., Shahid, N., Bajwa, K. S., Ashraf, M. A., ... & Husnain, T. (2015). Herbicide-resistant cotton (Gossypium hirsutum) plants: an alternative way of manual weed removal. *BMC research notes*, **8(1):** 1-8.
32. Maeder, M. L., Thibodeau-Beganny, S., Sander, J. D., Voytas, D. F., & Joung, J. K. (2009). Oligomerized pool engineering (OPEN): an'open-source'protocol for making customized zinc-finger arrays. *Nature protocols*, **4(10):** 1471-1501.
33. Mahgoub, S. E. (2016). *Genetically modified foods: Basics, applications, and controversy*. CRC Press.
34. Manickam, S., Guranjan, K. N., & Gopalakrishnan, N. (2008). Bt Cotton vis-à-vis environmental protection: an Indian perspective. *Central Institute of Cotton Research, Regional Station, Coimbatore*.
35. Manshardt, R. M. (1999). ‘UH Rainbow’ Papaya-A High-quality Hybrid with Genetically Engineered Disease Resistance.
36. MoEF & CC. 2016. Genetic Engineering Approval Committee. www.moef.nic.in/division/genetic-engineering-approval-committee-geac
37. MoEF & CC. 2017. INDIA Biosafety Clearing House. [accessed 2017 Nov 22]. https://www.geacindia.gov. in/india-bch.aspx
38. MoEF and BCIL New Delhi. 2015. Regulatory framework for genetically engineered (GE) plants in india. http://www.geacindia.gov.in/resource-documents/13_2
39. MoEF. 2010. Decision on commercialization of Bt brinjal. Minister’s report, Ministry of Environment and Forests, Govt. of India.
40. Moeller, L., & Wang, K. (2008). Engineering with precision: tools for the new generation of transgenic crops. *Bioscience*, **58(5):** 391-401.
41. Mohan, K. S., & Manjunath, T. M. (2002). Bt cotton-India's first transgenic crop. *Journal of Plant Biology-New Delhi*, **29(3):** 225-236.
42. Niu, L., Liu, F., Zhang, S., Luo, J., Zhang, L., Luo, J., Zhang, L., Ji, J., Gao, X., Ma, W., and Cui, J. (2020). Transgenic insect-resistant Bt cotton expressing Cry1Ac/CpTI

does not affect the mirid bug Apolygus lucorum. *Environmental Pollution*, **264:** 114762.
43. Nordlee, J. A., Taylor, S. L., Townsend, J. A., Thomas, L. A., & Bush, R. K. (1996). Identification of a Brazil-nut allergen in transgenic soybeans. *New England Journal of Medicine*, **334(11):** 688-692.
44. Pallett, K. (2021). The Current Status of GM and GE Crops. *Outlooks on Pest Management*, **32(2):** 50-52.
45. Park, S. Y., Vaghchhipawala, Z., Vasudevan, B., Lee, L. Y., Shen, Y., Singer, K., ... & Gelvin, S. B. (2015). Agrobacterium T-DNA integration into the plant genome can occur without the activity of key non-homologous end-joining proteins. *The plant journal*, **81(6):** 934-946.
46. Rashid, A. H. A., & Lateef, D. D. (2016). Novel techniques for gene delivery into plants and its applications for disease resistance in crops. *American Journal of Plant Sciences*, ***7*(1):** 181-193.
47. Regulatory_Framework_for_GE_Plants_in_India.pdf.
48. Rivera, A. L., Gómez-Lim, M., Fernández, F., & Loske, A. M. (2014). Genetic transformation of cells using physical methods. *Journal of Genetic Syndromes & Gene Therapy*, **5(4):** 237-242.
49. Shukla, M., Al-Busaidi, K. T., Trivedi, M., & Tiwari, R. K. (2018). Status of research, regulations and challenges for genetically modified crops in India. *GM crops & food*, **9(4):** 173-188.
50. Tzfira, T., & Citovsky, V. (2006). Agrobacterium-mediated genetic transformation of plants: biology and biotechnology. *Current opinion in biotechnology*, **17(2):** 147-154.
51. Venkatesh, S. (2020). *The Legality of Genetically Modified Crops and the Safety of Its Consumers in India* [Masters' dissertation, Alliance University]. Alliance School of Law. http://gnanaganga.inflibnet.ac.in/bitstream/123456789/333/1/Sourabha%20Venkatesh.pdf
52. Ziemienowicz, A. (2014). Agrobacterium-mediated plant transformation: Factors, applications and recent advances. *Biocatalysis and Agricultural Biotechnology*, **3(4):** 95-102.