

NG Agriculture Insights

A Popular Magazine (ISSN: 3107-5703)
Volume 2, Issue 6, November- December, 2026, 7-9

Variants Promising Assets Affliction and Future Prospects of Genetically Modified Crops in Modern Agriculture

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A B S T R A C T

Food security and sustainable crop production are severely hampered by the growing world population, climate change, and few agricultural resources. Through the creation of Genetically Modified (GM) crops, modern plant biotechnology has arisen as a useful strategy to address these issues. Crop modification is made possible by technologies like CRISPR-Cas9, RNA-interference (RNAi), and genetic engineering/recombinant DNA (rDNA). Productivity, nutritional value, pest and disease resistance, abiotic stress tolerance, and resource efficiency can all be enhanced by genetically modified crops. They also present chances to create crops with enhanced value and climate resilience. However, proper bio-safety evaluation, science-based regulation, and public awareness are necessary for their responsible use.

Keywords: *Genetic Engineering, rDNA, GM Crops, CRISPR-cas9, RNAi*

Submitted: 15-10-2026 Accepted: 01-11-2026 Online: 15-11-2026

1. INTRODUCTION

Genetic engineering is used to create genetically modified (GM) crops, often known as GMO or biotech crops, by introducing particular genes that confer desired characteristics including increased yield, resistance to pests and diseases, tolerance to herbicides and drought, enhanced nutrition, and extended shelf life. In contrast to traditional breeding, genetic engineering uses methods like gene gun (biolistic) technology and Agrobacterium-mediated transformation to directly introduce a desired gene into a crop (Mounika *et al*., 2022). The gene gun introduces DNA-coated gold or tungsten particles into plant tissues, whereas Agrobacterium tumefaciens naturally introduces DNA into plant cells.

Important crops including Bt cotton, Bt maize, and GM soybeans have benefited from GM technology, and research has also concentrated on crops like Golden Rice and GM mustard (Mounika *et al*., 2024). Insect pests, drought, nutritional shortages, and overuse of pesticides are some of the issues that these crops can help with. In 2025, GM crops were grown on roughly 216 million hectares in 30 countries worldwide (Harsha Vardhan *et al*., 2025). The United States, Brazil, Argentina, Canada, and India were among the top producers. As a result, genetic engineering is now a crucial technique for creating crops that are more nutritious, stress-tolerant, and prolific for sustainable agriculture (Vardhan *et al*., 2021).

https://doi.org/10.5281/zenodo.24239235

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Table 1. Global gm crops area by leading country in 2025

Rank	Country	GM area (M Ha.)	% Change	% Share
1	USA	75.2	-0.2	34.8
2	Brazil	70.0	3.1	32.4
3	Argentina	25.4	3.4	11.8
4	Canada	116	-0.5	5.4
5	India	10.6	-2.5	4.9
6	China	6.2	79.0	2.9
7	Paraguay	4.5	1.4	2.1
8	South Africa	3.3	0.3	1.5
9	Australia	2.1	1.3	1.0
10	Pakistan	1.9	-2.5	0.9
Na	Others	5.2	2.2	2.4
	Total	216.0	2.5	100.0

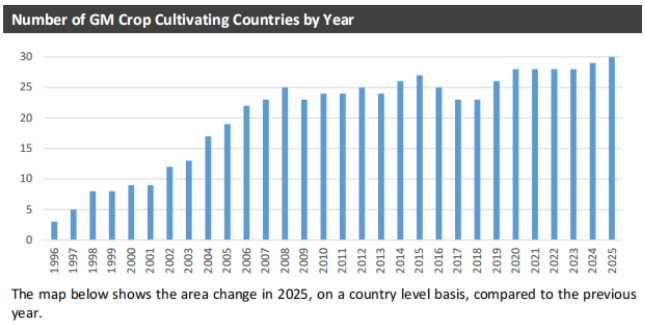


Figure 1. Number of gm crops cultivating countries by year

2. CONTEMPORARY GLOBAL STATUS OF MAJOR GM CROPS

Nowadays, in India, only BT Cotton is cultivated commercially. All other crops like BT Maize, BT Mustard, BT Soyabean, Golden Rice, and BT Rapeseed have not been approved by GEAC for commercial cultivation. All these crops except BT cotton are involved in legal issues in regard to their environmental safety, ecological diversity, accidental gene flow, and retention of natural heterogeneity of crops (Somvanshi, 2024).

2.1 Bt Cotton

Bt cotton is the first crop was commercially cultivated in the United States in 1996 and in India in 2002. This plant contains the Cry1Ac gene of Bacillus thuringiensis that encodes for Cry proteins, which are toxic to bollworm larvae of the cotton plants. In the gut of insects, these proteins are activated and cause damage to the gut wall, thus killing the insect. Bt cotton has played an important role in reducing insecticides and increasing the production of cotton. In India, Bollgard I was the first Bt cotton hybrid containing Cry1Ac, and Bollgard II had Cry1Ac and Cry2Ab and was extensively cultivated.

2.2 Bt Maize

The Bt maize, which was approved for commercial cultivation in the USA in 1996, provides resistance to key pests like the European corn borer, fall armyworm, corn earworm, and stem borers. It includes Cry genes of Bacillus thuringiensis such as Cry1Ab, Cry2Ab, and Cry1Fa, which encode insecticidal proteins. In addition, the first commercialized Bt maize included YieldGard® (Cry1Ab), while Event 176 and Event 1507 included Cry1Ab and Cry1Fa, respectively. However, despite widespread cultivation around the world, Bt maize is not approved for commercial cultivation in India.

2.3 GM Mustard

The research of GM mustard in India started in the 1990s through the use of barnase-barstar technology. The first GM mustard hybrid is DMH-11 that was created by Dr. Deepak Pental from the University of Delhi through crossbreeding of Varuna with Early Heera-2. DMH-11 is composed of barnase, barstar, and bar genes, which provide male sterility, fertility restorers, and glufosinate tolerance, respectively. This variety out-yields conventional varieties in field experiments and recommended by GEAC; however, its commercial production in India is still regulated by the country's policies.

2.4 Bt Soyabean

Bt soybean has been developed using hybridization between genetically modified plants, namely MON 87701 with insect resistance to Cry1Ac, and MON 89788 with glyphosate tolerance. It has a gene for the Cry1Ac protein of Bacillus thuringiensis and also has a gene that provides it with glyphosate tolerance called EPSPS. Recent varieties, such as MON 94637, have Cry1A.2 and Cry1B.2 proteins.

3. GOLDEN RICE

Golden Rice is an artificially modified crop which has been produced with the intention to cure vitamin A deficiency in people especially in those countries where rice is the primary source of food. Golden Rice was invented by Professors Ingo Potrykus and Peter Beyer and was introduced in the year 2000. It produces beta-carotene in the rice endosperm with the help of psy genes of daffodil and crtI of Erwinia uredovora. Golden Rice-2, which came in the year 2004, had psy1 gene and produced 20–23 times more beta-carotene than Golden Rice-1.

4. PROMISING ASSETS

Following is the explanation about how GM crops can be taken as promising assets.

i. **Elevated crop production:**

ii. GM crops have the potential to increase productivity because of the properties like pest resistance, herbicide tolerance, and stress tolerance, which would help minimize losses from crops (Somvanshi, 2024).

iii. **Biofortified crops:**

Genetically modifying staple food plants can increase their nutritional quality through adding more of these essential nutrients (8). For instance, "golden rice" contains Beta-carotene, which is a precursor of Vitamin A (Ahtisham and Obaid., 2024).

5. VALUE ADDED INDUSTRIAL TRAITS

The genetic modification technique can also contribute to enhancing the quality and processing of crops by altering the content of oil, starch, protein, and fiber (Somvanshi, 2024). These attributes can boost the value of agriculture-based products.

6. AFFLICTION OF GM CROPS

i. **Ecological consequences**
Repeated planting of genetically modified crops may cause resistance to pests and herbicides, gene flow, impacts on non-target organisms, and decreased biodiversity.

ii. **Cost related concerns:**
The high cost of genetically modified seeds, the intellectual property right issue, and reliance on seed suppliers can raise production costs, especially among smallholder farmers.

iii. **Potential health risks:**
Though the safety of approved GM crops is assessed, the possible risks that include allergenicity and unintended consequences need scientific evaluations

7. CONCLUSION

The genetically modified crops have vast possibilities for improving crop yield, nutrition content, stress resistance, and food security. The further development of genetically modified crops in India depends on further research, bio-safety analysis, regulatory frameworks based on science, and public education. Further developments in the field of genome editing like CRISPR-Cas9 can be used for developing new climate resistant crops.

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