

Global Adoption Trends, Health Consequences, and Public Perception of Genetically Modified Crops in Sustainable Agriculture

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ABSTRACT

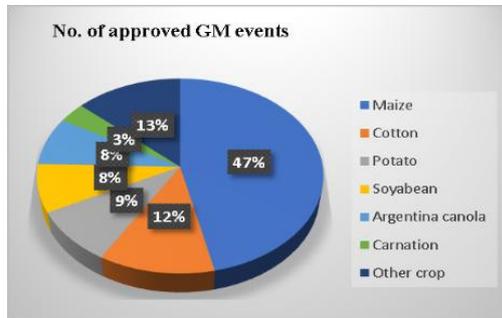
Genetically modified (GM) crops contribute significantly to sustainable agriculture by increasing yields, enhancing tolerance to pests, diseases, and environmental stresses, and reducing reliance on chemical pesticides. Currently cultivated in 29 countries across nearly 190 million hectares, major GM crops such as soybean, maize, cotton, and canola show particularly high adoption in the Americas and India. Their cultivation has improved farmer incomes and reduced production costs. Bt-based crops have also lowered pesticide exposure, benefiting farm workers' health. However, concerns related to allergenicity, antibiotic resistance, long-term health risks, and public acceptance persist, highlighting the need for rigorous biosafety evaluation and transparent scientific communication.

INTRODUCTION

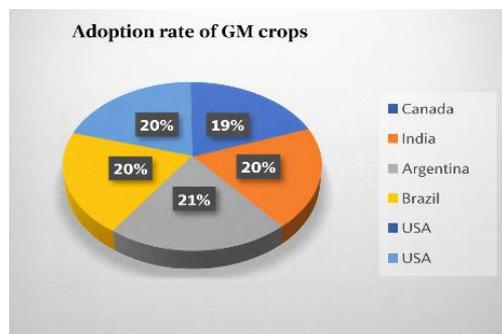
Sustainable agriculture must balance global food security with environmental protection and farmer welfare. Genetically modified (GM) crops have emerged as a key strategy to achieve these objectives by improving nutritional quality and

enhancing resistance to pests, diseases, and abiotic stresses. Over the past 25 years, GM crop cultivation has expanded more than 100-fold, reaching nearly 190 million hectares worldwide (figure.1). Major GM crops include soybean, maize, cotton, and canola, widely

used for feed and industrial purposes. Although widely adopted and technologically advanced, GM crops continue to face regulatory, ethical, and public acceptance challenges, particularly in Europe and the Middle East (Sandhu *et al.*, 2025).



(a)



(b)

Figure 1. Global evolution of genetically modified (GM) crops: acceptance and prevalence patterns. Global distribution of authorised GM events across major crop groups and GM crop adoption rates by nation between 1996 and 2022 (Adapted from Sandhu *et al.*, 2025).

Current Status

Over 190 million hectares of commercially grown genetically modified crops are spread across 29 nations. The top producers are India, Canada, Argentina, Brazil, and the United States. The main GM crops are canola, maize, and soybeans; adoption rates are especially high in North and South America. In 2019, GM soybeans accounted for 74% of global soybean acreage, while GM maize represented 31% of total maize cultivation. Argentina has

achieved nearly 100% adoption of biotech crops, and Brazil's GM soybean cultivation has reached approximately 95%, reflecting near saturation. In contrast, GM crop cultivation in Europe remains limited and continues to decline. By 2022, only about 1% of Europe's agricultural land was devoted to GM crops, mainly Bt maize in Spain and Portugal. Despite low cultivation levels, the European Union increasingly authorises GM crop imports for food and feed use, indicating growing dependence on global GM production (Waiblinger *et al.*, 2023).

➤ Potential Benefits of GM-Derived Products:

• Food Security and Economic Advantages

Proponents argue that GM crops can contribute to reducing global hunger, although this perspective has generated mixed reactions. Long-term research indicates that GM crops have improved agricultural productivity and contributed to global food security. Between 1996 and 2011, farmers' incomes worldwide increased significantly due to GM crop adoption, primarily through improved weed and insect control, higher yields, and reduced production costs. The greatest economic benefits were observed in countries such as the United States, Argentina, China, and India. Nevertheless, debates regarding the overall socio-economic impact of GM crops continue (Karalis *et al.*, 2020).

• Advances in Insect, Nematode, and Herbicide Resistance

Bacillus thuringiensis (Bt) is a Gram-positive soil bacterium widely used as a biological pesticide. During sporulation, it produces crystal (δ -endotoxin) proteins with strong insecticidal properties. Bt genes have been introduced into crops such as maize to control pests like the European corn borer, which causes substantial yield losses worldwide.

Parasitic nematodes also significantly damage crops by attacking root systems and persisting in soil for extended periods. Chemical nematicides pose environmental risks, and crop rotation can be economically burdensome. Incorporating nematode-resistant genes into crops therefore represents a promising alternative. Herbicide-tolerant GM crops, such as glyphosate-resistant soybean, express modified enzymes that allow survival after herbicide application. While these innovations reduce certain pesticide applications, concerns about long-term environmental and health impacts remain (Karalis *et al.*, 2020).

- **Cold and Heat Stress Tolerance**

An important benefit of GM technology is the development of crop varieties tolerant to temperature extremes. Rapid climate change and unpredictable temperature fluctuations have limited the natural adaptive capacity of many crops. Researchers have therefore focused on developing transgenic varieties capable of tolerating cold and heat stress. Genetic modifications targeting specific metabolic pathways may help sustain crop productivity under future climate scenarios (Karalis *et al.*, 2020).

- **Human Health Issues, Agricultural Pesticide Use, and GM Crop Interventions:**

Repeated application of chemical insecticides in crops such as cotton and brinjal increases the risk of pesticide poisoning among agricultural workers. A medical study involving 246 Chinese agricultural workers reported associations between fungicide exposure and liver damage, as well as potential neurological effects from insecticides. In contrast, Bt cotton cultivation requires fewer chemical applications, reducing pesticide exposure and related health risks. Despite

these advantages, global pesticide usage reached approximately 3.5 million metric tonnes in 2021 (Sandhu *et al.*, 2025).

- **Health Hazards and Chronic Illness Concerns**

Concerns regarding the long-term health impacts of GM crops persist. Some critics argue that the transfer of antibiotic resistance markers or foreign genes may pose potential risks. Although substantial scientific evidence supports the safety of approved GM crops, uncertainty about long-term consumption effects contributes to public scepticism (Sandhu *et al.*, 2025).

- **Allergenicity and Genetic Safety**

Concerns have also been raised regarding allergenicity. A well-known case involved the transfer of the 2S-albumin gene from Brazil nut into soybean, which resulted in allergic reactions during testing. This case demonstrated the importance of rigorous allergenicity screening prior to commercial release. Additionally, theoretical concerns regarding horizontal gene transfer and potential carcinogenic effects continue to be examined through biosafety assessments (Sandhu *et al.*, 2025).

- **Public Perception Across Regions**

Public perception of GM foods varies significantly across regions. In China, although a majority of respondents reported unknowingly consuming GM products, perceptions of safety remained divided. In Bangladesh, most Bt brinjal farmers considered the crop safe for consumption. Education level and awareness strongly influence acceptance, underscoring the importance of effective science communication and transparent regulatory frameworks (Sandhu *et al.*, 2025).

CONCLUSION

Genetically modified crops support sustainable agriculture by increasing yields, enhancing resistance to pests and environmental stresses, and reducing pesticide use. Their global adoption demonstrates significant agronomic and economic benefits. Bt technology has improved farm safety by lowering pesticide exposure. However, ongoing concerns regarding allergenicity, antibiotic resistance, long-term health effects, and ethical considerations necessitate transparent biosafety evaluations and responsible scientific communication to ensure sustainable integration.

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