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Review Article

The Role of Transgenic Plants in Ensuring Food Security: A Review

Qari Sidiqullah Faizi

Academic Member of research center of Chemistry, Biology and agriculture.

ASA (Afghanistan Sciences Academy)Kabul, Afghanistan

Abstract: Food security means ensuring that all people have sufficient, safe, and nutritious food to live healthy lives, and it remains one of the greatest global challenges. Transgenic plants, as a modern agricultural tool, offer significant potential to address this issue. This review evaluates their role in improving food security, with emphasis on Afghanistan. The analysis is based on scientific books, polished peer-reviewed journals, and national and international research. Findings show that transgenic plants, with traits such as pest and disease resistance, tolerance to drought and salinity, and improved nutritional quality, can substantially increase yields. In Afghanistan, where agriculture is central to the economy yet highly vulnerable to climate change, water scarcity, and low productivity, these crops could enhance food self-sufficiency, reduce imports, and strengthen rural livelihoods. Their use may also reduce pesticide and fertilizer reliance, lower greenhouse gas emissions, and contribute to sustainable agriculture and environmental protection.

Keywords: *food security, genetically modified crops, global agriculture*

1. Introduction

According to the Food and Agriculture Organization (FAO) in 2019, more than 870 million people worldwide continue to suffer from hunger and malnutrition, with the most severe crises occurring in developing countries. Nations such as Afghanistan, Nigeria, South Sudan, the Democratic Republic of Congo, Ethiopia, and Syria remain particularly vulnerable to food insecurity. Afghanistan's situation is aggravated by decades of conflict, climate variability, limited arable land, and chronic water scarcity. FAO projections indicate that the global population will approach nine billion by 2050, requiring a minimum 70 % increase in food production to meet demand (FAO (2026). *FAO GIEWS Country Brief – Afghanistan*. Food and Agriculture Organization of the United Nations.

Biotechnology offers one of the most promising avenues to achieve this goal. Transgenic plants commonly known as genetically modified (GM) crops are created through recombinant DNA technology, allowing the stable insertion of beneficial genes from other plants, bacteria, or even animals (Chawla, 2009). These crops can be engineered for pest and disease resistance, drought and salinity tolerance, and enhanced nutritional quality, making them well suited to the harsh agro-ecological conditions of Afghanistan's semi-arid regions.

Extensive international studies demonstrate that GM crops can reduce pesticide use, lower production costs, and improve both yield and food quality, while mitigating environmental impacts such as soil degradation and chemical pollution (Karami & Farzad, 2013). The FAO defines genetically modified foods as those whose genetic material has been altered using modern molecular methods beyond natural recombination. Recombinant DNA technology provides a more precise and rapid mean of introducing desirable traits compared with conventional breeding.

For Afghanistan, where agriculture contributes roughly one-quarter of GDP and employs over 60 % of the population, adopting transgenic crops could directly strengthen food security.

However, successful deployment will require robust biosafety regulations, public awareness campaigns, and regional collaboration to ensure environmental safety and consumer acceptance. A balanced policy framework combining scientific evidence, farmer training, and clear regulatory oversight can enable Afghanistan to harness transgenic technology as part of a broader strategy to achieve sustainable food self-sufficiency and meet the

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Corresponding Author: Qari Sidiqullah Faizi

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United Nations (UN) Sustainable Development Goal of "Zero Hunger" by 2030.

Food security is essential for global stability, human well-being and long-term prosperity. According to the 2023 Report on the State of Food Security and Nutrition in the World, food crises continue to occur in some nations and areas, and global food security remains a critical issue. The variables that threaten food security include natural disasters, escalating regional tensions, and severe climate change (**FAO, IFAD, UNICEF, WFP, & WHO.** (2023Report).). Traditional crop production methods are becoming increasingly challenged by a variety of factors, including climate fluctuations, limited land resources, and an overreliance on chemical fertilizers and pesticides, resulting in volatility and significant environmental pressure. As one exciting development, the introduction of genetically modified (GM) crops has been shown to improve resilience, successfully alleviate restrictions, conserve the environment, and improve the quality and nutritional value of agricultural products, thereby encouraging the adoption of green agriculture and adding fresh vitality to global food security. The industrialization of GM crops has resulted in positive economic and environmental outcomes (ISAAA, 2019). This article analyzes the global commercialization of GM crops from 1996 to 2023, based on data from the ISAAA and government websites. It identifies the endogenous driving forces behind the increases in planting area and the number of GM crops.

According to the United States Department of Agriculture (USDA) elucidated that food insecurity pertains to a situation whereby access to safe, healthy, and nutritious meals is restricted, uncertain, limited, or unpredictable, as well as the capacity to acquire acceptable foods through socially acceptable means. This is a disheartening reality in many regions of the world. Currently, there are about 8 billion people on planet Earth. It is unfortunate that about 1 billion people languish through under nutrition, living daily in hunger, and that 2 billion more people suffer from essential micronutrient deficiencies. In the face of diminishing land availability for agriculture and food production due to industrial and construction activities, the world is left with no alternative but to seek means to maximize the limited resources available and produce more food from the fast depleting farmlands and the small amount of irrigation water. As a result, the requirement for additional food must be addressed by increasing yields per unit of resource input (land, water, energy, and time). Coleman-Jensen, et.al. (2023). It becomes imperative to examine how science can be de played to increase productivity ceilings with no further harm to the ecosystem **(**ISAAA (International Service for the Acquisition of Agri-biotech Applications (2019).A need that biotechnology duly meets. Achieving food security is a matter of global urgency and all hands must be on deck. Several international agreements and institutions have been formed to this end. The Sustainable Development Goals (SDGs) are the main worldwide policy for reducing hunger and poverty. The second goal of the SDG, tagged 'The Zero Hunger Initiative', aims to achieve a set of universally agreed-upon goals that will put an end to hunger, ensure food security and improve nutrition, and promote sustainable agriculture by the year 2030. A question still needing an answer is how this can be achieved within a limited time and with limited resources. Biotechnology is a promising solution. (USDA, 2023).

2. Materials and Methods

This study employed a descriptive analytical review designed to examine the role of transgenic (genetically modified) plants in ensuring food security, with special reference to Afghanistan. Data were collected from peer-reviewed scientific journals, international research reports, academic books, and reputable global databases (e.g., FAO, ISAAA, Scopus, and Web of Science) published in both English and Persian/Dari. Sources included experimental research papers, meta-analyses, and review articles that address the agronomic performance, nutritional quality, environmental impacts, socio-economic outcomes, and biosafety considerations of transgenic crops.

3. Importance of Transgenic Plants

Transgenic plants, or genetically modified organisms (GMOs), refer to organisms in which new genes have been introduced into their genetic structure through genetic engineering. These modifications are usually carried out with the aim of improving desirable traits.

Agricultural biotechnology is a modern science that has moved beyond basic research to become an established field worldwide, capable of improving quality of life, particularly in developing countries. The use of genetic engineering to transfer desirable genes into plants is referred to as creating transgenic plants. Plants developed in this way, possessing traits such as higher nutritional value, improved shelf life, and resistance to pests, viruses, and other stresses, are known as transgenic.

The production of transgenic plants through various gene transfer methods aims to introduce traits such as enhanced shelf life, resistance to diseases, pests, drought, and herbicides, production of pharmaceuticals, the ability to absorb toxins, and applications in environmental pollution remediation.

Importance of Transgenic Plant

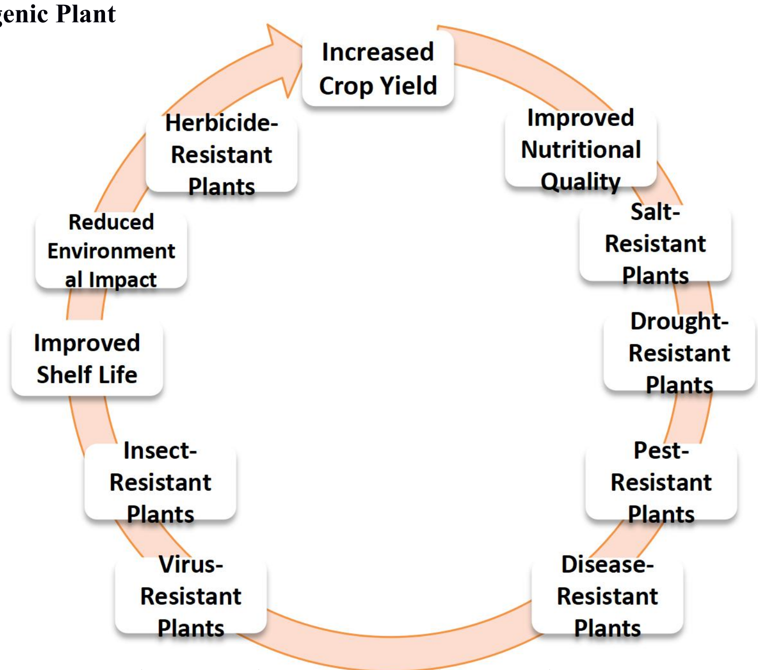

Fig.1. some important uses of Transgenic crops

Source: (Shetty, P. K., et al. (2020).

4. Benefits of Transgenic Plants in Ensuring Food Security, Promoting Sustainable Development, and Addressing Climate Change Challenges

Transgenic plants possess the ability to grow under harsh climatic conditions and exhibit resistance to pests and disease**s.** These crops can reduce the need for chemical pesticides and other agrochemicals, thereby increasing overall agricultural productivity. Consequently, they contribute to improvements in the quantity, quality, and utilization of food. Some of the benefits of transgenic plants are outlined below:

- **Economic Impact**

Among the major advantages of transgenic crops is their contribution to sustainable economic growth through enhanced food security, reliable supplies of animal feed, textile raw materials, and provision of low-cost food, thereby helping to alleviate poverty and hunger. In addition, improved weed management and higher yields of transgenic crops are largely attributable to lower production costs resulting from reduced field operations, fewer pesticide applications, and decreased labor expenses which ultimately lead to more affordable food prices. The principal commercially successful traits of agricultural transgenic plants to date are resistance to herbicides and insects (Brookes, G., & Barfoot, P. (2022).

- **Environmental Impact**

Between 1996 and 2020, the cultivation of transgenic crops reduced the use of chemical pesticides by approximately 748.6 million kilograms. Although chemical pesticides remain an inseparable component of modern agriculture, their application imposes costs at both household and national levels and poses health risks to farmers because of pesticide residues as well as to consumers. However, the negative effects of chemical pesticides on non-target organisms, including natural enemies of pests, are unavoidable.

Currently, most transgenic plants worldwide possess traits conferring resistance to pests, herbicides, and fungal and viral diseases. In addition, transgenic crops can contribute to the **low-**cost production of biofuels, mitigation of climate change, prevention and conservation of water resources, and reduction of greenhouse gas emissions. The increased yields of transgenic crops have also saved approximately 183 million hectares of land**,** ultimately helping to prevent deforestation and protect biodiversity (Brookes & Barfoot, 2022; Pak & Khosravipour, 2016; Khosravi & Tohidfar, 2012; Mohammadi & Yazdanpanah, 2013).

- **Social Impact**

The social dimension is among the most important objectives in the production and dissemination of transgenic crops. These products can address social needs by providing safe and nutritious food, reducing poverty, lowering environmental impacts, controlling human diseases, improving public health, supplying

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inexpensive raw materials, and enhancing conditions in developing countries as well as global nutrition.

Moreover, transgenic crops contribute to poverty alleviation and increased household income**,** which in turn enables better access to healthcare and education for community members, thereby fostering broader social development ((Pak & Khosravipour, 2016; Khosravi & Tohidfar, 2012).

- **Impact on Health**

Millions of people around the world currently consume foods derived from various transgenic plants such as soybean, cotton, maize, canola, and others. To date, no reports have documented toxic or harmful effects on humans or animals from the consumption of these genetically modified foods.

Some genetically engineered products specifically designed for human consumption offer distinct nutritional benefits, including higher protein content, modified and health-promoting fats, adjusted carbohydrates, enhanced flavor and aroma characteristics, and increased antioxidant levels. Modifying the quantitative and qualitative composition of nutrients such as proteins, starch, fats, or vitamins through metabolic-pathway engineering can raise the nutritional value of food and help alleviate chronic malnutrition, thereby improving human health. (Heydarijapalaghi & Ebrahim Dorrani, 2016; Mohsenpour et al., 2018; Mohammadi & Yazdanpanah, 2013; Nielsen et al., 2000).

Vitamin A deficiency alone causes partial or complete blindness in roughly half a million children each year (Rani & Usha, 2013). To address this regional health challenge, scientists transferred vitamin A precursor genes used in *Golden Rice* into a locally popular crop variety. Correcting such vitamin deficiencies can reduce healthcare costs and enhance economic productivity.

In addition, the production of vaccines in transgenic plants, followed by oral administration, is emerging as an attractive option because it eliminates the need for fermentation, purification, cold-chain storage, and sterile transport all of which entail high costs (Juma, C., & Gordon, M. B. (2014).

- **Managerial-Political Impact**

Demonstrated that, from the perspective of experts, the highest priorities for increasing both the quantity and quality of transgenic crop production are: coordination of relevant institutional programs, establishment of strong managerial systems and plans, raising awareness and providing support to farmers, and addressing legal and political barriers.

5. Disadvantages of Transgenic Crops

Although transgenic products play an important role in ensuring food security, they also have potential disadvantages and risks, some of which are outlined below:

1. There is a possibility of allergies in consumers of transgenic agricultural products.
2. Transgenic varieties may replace local or indigenous crop varieties.
3. They may result in the emergence of resistant weeds, which can proliferate in main agricultural fields.
4. These products may cause the development of insects that are resistant and highly resilient to pesticides.
5. In some cases, they may potentially contribute to the development of cancer in human organs.

It should be noted that transgenic foods currently available in international markets have undergone safety evaluations and are unlikely to pose a risk to human health and the environment. However, the absolute safety of all transgenic foods cannot be confirmed with certainty. But up to now, no adverse effects on human health have been observed from the consumption of these foods by the general population in countries where they have been approved (National Academies of Sciences, Engineering, and Medicine. (2016).And World Health Organization (WHO). (2020).In recent years, research has focused on the fundamental role of plant genetic resources and germplasm in crop breeding, particularly in relation to traits such as yield, resistance, and adaptation to environmental stresses. Studies have emphasized the importance of maintaining the diversity of these resources and the use of advanced methodologies for their evaluation and utilization. Furthermore, the application of modern biotechnological tools, including molecular markers, genetic mapping, and genome-wide association studies, has facilitated the effective characterization, conservation, and exploitation of plant genetic resources .Such approaches provide critical information for crop improvement programs and the sustainable management of genetic diversity. (Xu, Y. (2010). Collard & Mackill (2008).

6. Farmer Adoption of Transgenic Crops

The adoption of transgenic crops by farmers has been increasingly documented worldwide, driven by the promise of higher yields, enhanced pest and disease resistance, and improved tolerance to abiotic stresses. In regions where farmers have access to reliable information, technical support, and market incentives, the acceptance of genetically modified (GM) crops has been generally positive. Studies indicate that farmer perceptions are influenced not only by the economic benefits but also by concerns regarding environmental safety, regulatory compliance, and long-term sustainability. In the context of Afghanistan, initial surveys and field trials suggest that where GM crops are introduced under proper guidance and support, farmers show a willingness to adopt these crops, particularly when they offer solutions to prevalent agricultural challenges such as pest infestation, drought, and low soil fertility (Shetty et al., 2017; FAO, 2015).

Between 1996 and 2003, research on genetically modified organisms (GMOs) primarily focused on their development, evaluation, and field performance. Early studies lacked sufficient data, limiting conclusive assessments. By 2002, however, preliminary evidence indicated notable progress, and by 2003, significant advancements were documented, with approximately 85% of evaluated GMOs exhibiting the intended genetic traits. These early assessments highlighted improvements in crop resilience and performance under various environmental conditions.

By November 2013, 54 studies had been conducted on GM crops, providing a substantial evidence base for their agronomic and technological impact. Nationwide surveys conducted in 2014 revealed that GM research predominantly targeted technological innovation, with 37 trials on staple crops and 22 trials on other crop varieties. These studies demonstrated measurable improvements in yield, pest resistance, and stress tolerance (Shetty et al, 2016 & 2017). Collectively, these findings underscore the significant contribution of GM crops to agricultural productivity and sustainability. A selection of genetically engineered (transgenic) crops that have received regulatory approval worldwide is presented in the Table below, highlighting their commercial adoption and global significance.

Table 1. List of transgenic crop varieties and their corresponding crop species.

No of transgenic varieties	Crop Scientific Name
2	*Oryza sativa L.*
3	*Triticum aestivum*
4	*Zea mays L.*
5	*Gossypium hirsutum L.*
6	*Phaseolus vulgaris*
7	*Vigna unguiculata*
8	*Malus x Domestica*
9	*Solanum melongena*
10	*Glycine max L.*
11	*Linum usitatissimum L.*
12	*Prunus domestica*
13	*Solanum tuberosom L.*
14	*Populus sp.*
15	*Cucurbita pepo*
16	*Beta vulgaris*
17	*Saccharum sp.*
18	*Capsicum annum*
19	*Nicotiana tabacum L.*
20	*Dianthus caryophyllus*
21	*Cucumis melo*

Source: (global GM crop data (2023–2025).

7. Developmental Pathway of Genetically Modified (GM) Crops

The development of genetically modified (GM) crops is rooted in early agricultural practices that began approximately 10,000 years ago with artificial selection and selective breeding. Early farmers selected plants with desirable traits, gradually improving crop yield, quality, and adaptability over generations. For example, modern maize was domesticated from wild grasses such as *teosinte*, resulting in significantly larger ears and higher kernel numbers (Doebley, 2006; Raman, 2017).

Modern genetic modification began in the 20th century with key scientific breakthroughs. In 1944, the role of DNA as the genetic material was demonstrated, and later, the discovery of the double helix structure of DNA by James Watson and Francis Crick in 1953 revolutionized molecular biology (Cobb, 2017). These discoveries led to the formulation of the central dogma of molecular biology, describing the flow of genetic information from DNA to RNA to protein.

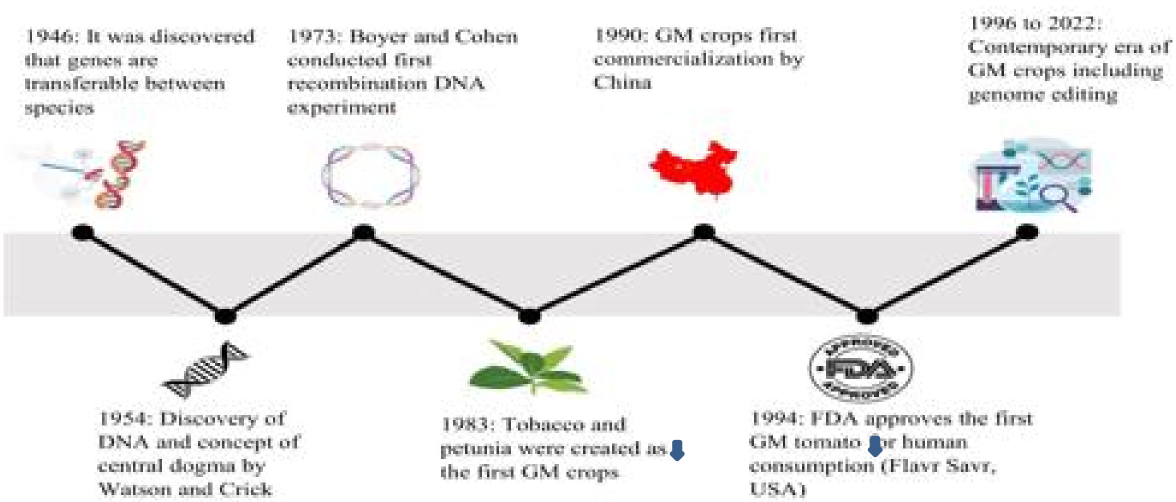
A major milestone occurred in 1973 when Stanley Cohen and Herbert Boyer successfully developed recombinant DNA technology, enabling the transfer of genetic material between organisms (Cohen et al., 1973). This breakthrough marked the beginning of modern genetic engineering.

In 1983, the first genetically modified plants, including tobacco and petunia, were successfully developed using Agrobacterium-mediated transformation, introducing antibiotic resistance genes (Fraley et al., 1983). In 1994, the Food and Drug Administration approved the Flavr Savr tomato, developed by Calgene, as the first GM crop for human consumption (Vega Rodríguez et al., 2022). This tomato utilized antisense RNA technology to suppress the enzyme polygalacturonase, thereby delaying fruit ripening and reducing spoilage (Bawa & Anilakumar, 2013).

During the mid-1990s, several GM crops were commercialized, including:

- Bt cotton and Bt maize, engineered with genes from Bacillus thuringiensis for insect resistance
- Roundup Ready soybean, developed by Monsanto for glyphosate herbicide tolerance
- GM canola, developed for improved oil quality

Since then, genetic engineering has expanded to a wide range of crops including rice, wheat, maize, soybean, sugarcane, fruits, and vegetables. Modern GM technologies are used not only to improve yield and pest resistance but also to enhance nutritional quality, abiotic stress tolerance (such as drought and salinity), and industrial and pharmaceutical applications, including vaccine production in plants (Kurup & Thomas, 2020).



Source :(Baqizada.*et.al*, 1397).

Fig (1): Developmental Pathway of Genetically Modified (GM) Crops

8. Global area planted with GM crops

In 2023, genetically modified (GM) technology was adopted in 76 countries and regions, with approximately 206.3 million hectares cultivated across 27 countries, representing a 3.05% increase compared to the previous year

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(AgbioInvestor, 2024). Since 1996, the global GM crop area has expanded more than 120-fold and now accounts for about 13% of the world's total arable land (FAO, 2023; ISAAA, 2023). As illustrated in Figure 1, developed countries initially dominated GM crop cultivation prior to 2011. However, by 2011, adoption levels between developed and developing countries became nearly equal. Since 2012, developing countries have consistently exceeded developed countries in GM crop area. By 2023, developing countries accounted for approximately 54.78% of the total GM crop area, surpassing developed countries by nearly 19.8 million hectares (AgbioInvestor, 2024).

Table 2. Changes in the area planted with genetically modified (GM) crops in various countries and regions.

Region	**GM area (Million ha)**	**Country**	**GM area (million ha)**
North America	85.90	United states	74.40
		Canada	11.50
		Brazil	66.90
Central and South America	97.32	Argentina	23.10
		Paraguay	4.30
		Bolivia	1.50
		Uruguay	1.20
		Colombia	0.20
		Honduras	0.10
		Chile	0.01
		Mexico	0.01
Asia Pacific	19.50	India	2.80
		China	2.30
		Pakistan	1.40
		Australia	0.60
		Philippines	1.40
		Vietnam	0.20
		Myanmar	0.10
		Indonesia	0.02
		Bangladesh	0.003
others	3.57	South Africa	3.31
		Sudan	0.20
		Ethiopia	0.01

Source: (Agbio Investor, 2024)

9. Changes in the planting areas of GM crops in different countries and regions

The top five countries in terms of planting area (the United States, Brazil, Argentina, India, and Canada) represented 91% of the world's GM crops. According to Table 2, five of the 27 planting countries, Brazil, Canada, Paraguay, South Africa, and Pakistan, have expanded their planting areas over the previous year. Pakistan experienced the largest increase, at a rate of 33.30%, whereas the planting areas for GM crops in the United States, Argentina, India, and China have fallen marginally (Fig. 1).

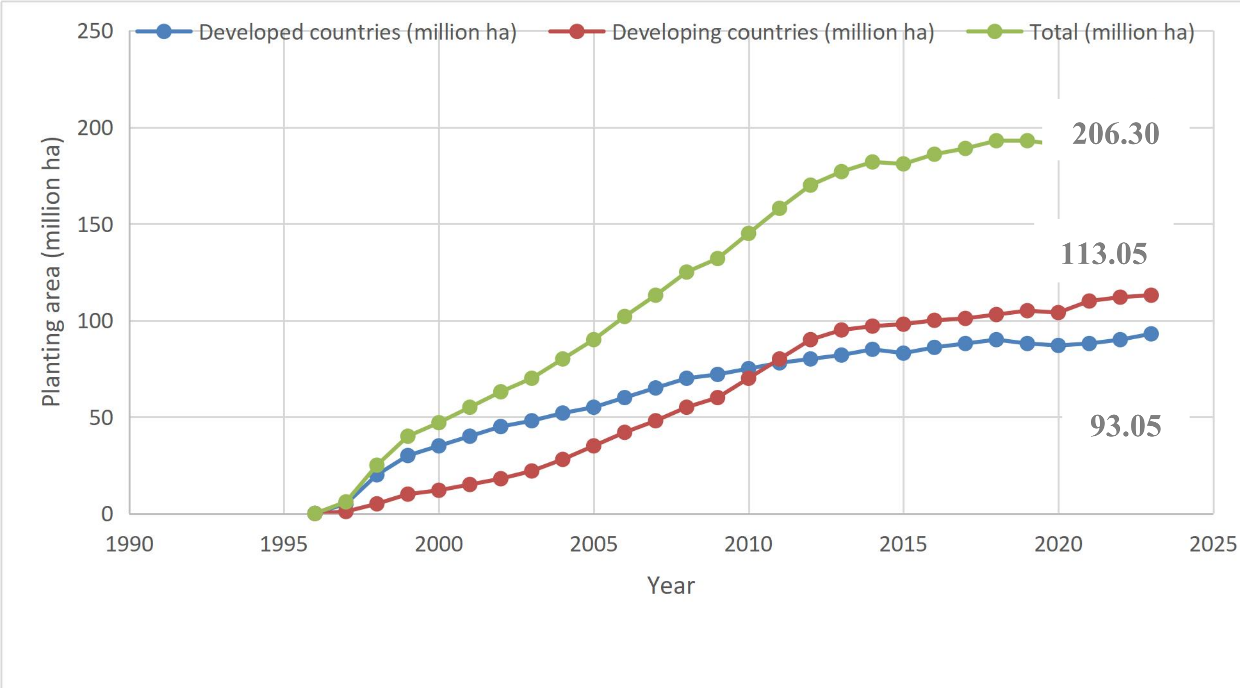


Fig. 2. Trends in the global planting area of genetically modified (GM) crops, 1996-2023.

Source: (ISAAA 2019 Agbio Investor 2024).

10. Global adoption rates and cultivation area of major GM crops (2023)

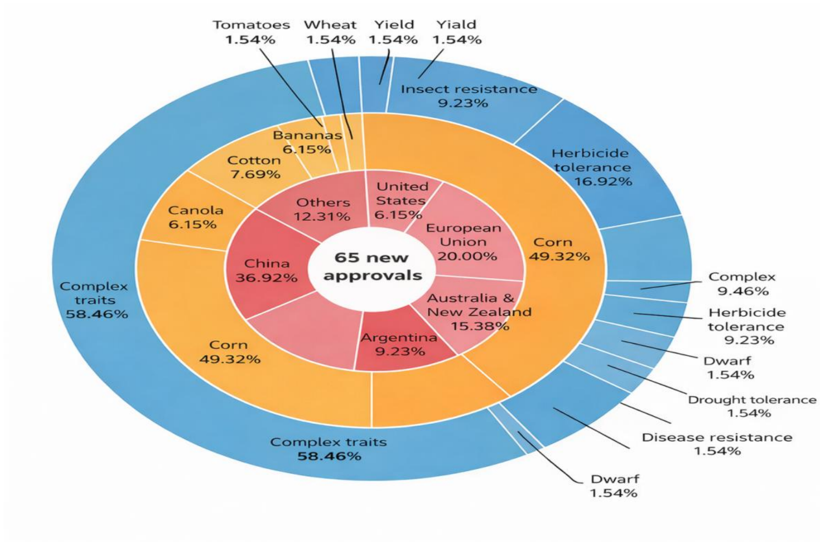


Fig.3. Distribution of 65 New GM Crop Approvals by Region, Crop Type, and Trait

As shown in Fig. 3, cotton, soybean, corn, canola, sugar beet, alfalfa, sugarcane, eggplant, rice, and wheat were the GM crops planted globally in 2023. GM soybean (100.9 million hectares) and GM corn (69.3 million hectares) remained dominant, with their planting areas increasing by 2.02 and 4.68% from the previous year, and adoption rates of 72.4 and 34%, respectively. In third place, 24.10 million hectares of GM cotton were planted, representing a

5.12% reduction from the previous year, and an adoption rate of up to 76%. Next, 10.20 million hectares of GM canola were planted, up 3.03% from the previous year, with a 24% adoption rate.

11. Suitable traits of GM crops in different regions

Central and South America is the Region with the largest area of GM crops, primarily GM corn, soybean and cotton, and it saw a 4.1% increase in the GM crop planting area in 2023 compared to the previous year. Most of that increase was due to GM corn, soybean and cotton with insect- and herbicide-resistant composite traits, and they now have adoption rates of more than 95%. North America canola has GM adoption rate of more than 90%. The Asia-Pacific area largely planted GM cotton with insect resistant characteristics, with the GM cotton adoption rate remaining at 95% (ISAAA, 2020; AgbioInvestor, 2024).

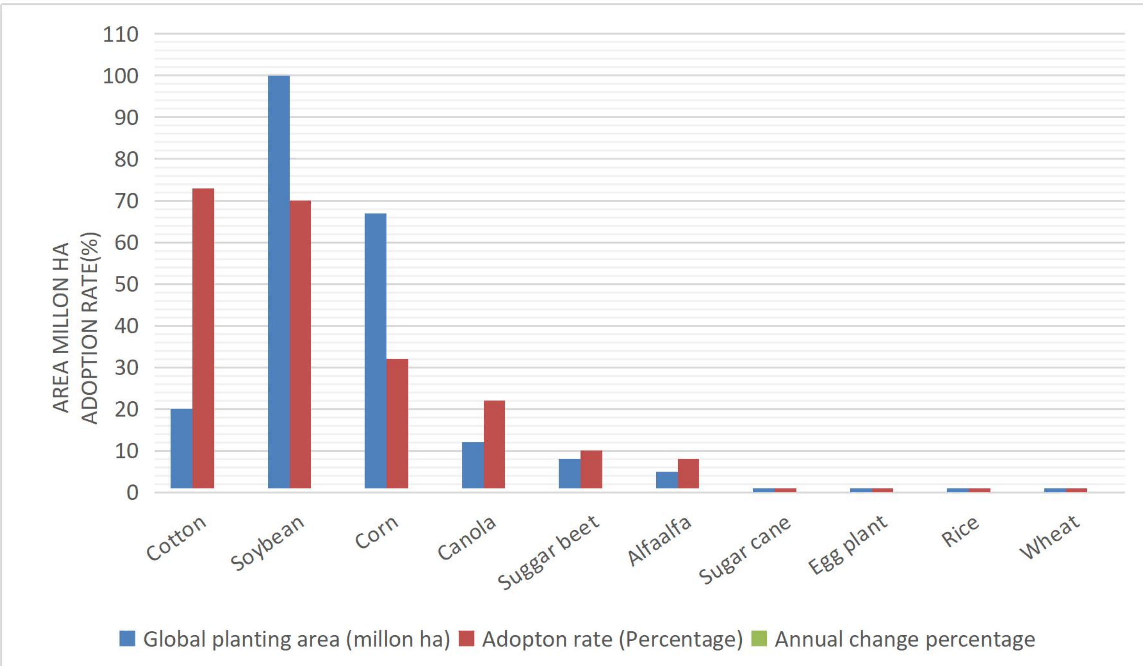


Fig. 4. Global adoption of genetically modifed (GM) crops (Agbio Investor 2024).

the second largest planting area for GM corn, soybean, cotton, and canola in 2023, but it showed a 0.1% reduction from the previous year. In this area, more than 80% of GM corn and cotton contained the insect- and herbicide resistant traits, while GM soybean and canola only had the herbicide-resistant traits. Corn, soybean, cotton,

Newly approved GM crop transfor mants in various countries and regions As shown in Fig. 3, below, 65 GM crop transformants were approved for use in food, feed, processing or cultivation, with the majority coming from China (36.92%), the European Union (20.00%), Food Standards Australia New Zealand (15.38%), Argentina (9.23%), the United States (6.15%), and other nations. In terms of crops, corn continues to have the most approved transformants, at 49.32%, followed by soybean (32.31%), cotton (7.69%), canola (6.15%), and others. For the converted traits, the proportion of compound traits accounted for 58.46%, while the proportions of individual insect resistance or herbicide resistance traits were 9.23 and 16.92%, respectively. Furthermore, several countries and areas

have adopted the layout of “new” GM features, such as drought tolerance, short stalks and disease resistance.

12. Global import and export trade in GM crop products

Increasingly, countries have begun to cultivate GM crops and integrate them into their import and export systems for food due to the ongoing development and application of GM technology. GM crops have become a significant component of the food exports from certain key countries, including the Fig. 3.

Correct spellings of canola, corn, European

Fig 3. Approved GM Crops in different countries and regions as well as the respective GM traits

United States, Brazil, and Argentina, which are known for their large-scale production of GM crops. Conversely, countries and regions in Asia, including the Republic of Korea, Japan, and China, are significant importers of GM crops due to their high demand for food, limited land resources, and large populations. The issue of irregular global food distribution has been effectively resolved through the global trade of GM crops, which has also contributed to guaranteeing the food security of the global food cycle. Nevertheless, the export of GM crops products will create price disparities in the markets of the importing countries, and pose a challenge to local industries due to the low production cost and high returns of the GM crops.

Figure 5. Essential components of food security.

Meeting the world’s rising food demand is a major global challenge, particularly in Africa, where agricultural sustainability is essential for achieving long-term food security (FAP (2022). Current agricultural production systems and conventional technologies are insufficient to meet the increasing demand driven by rapid population growth, making this a critical global concern (FAO (2018). Food security is generally defined through four key dimensions: availability, accessibility, utilization, and stability. Food availability refers to the presence of sufficient quantities of high-quality food, whether produced domestically or obtained through imports. Food accessibility ensures that individuals can obtain adequate food of acceptable quality at affordable prices. Food utilization relates to the proper biological use of food, requiring safe and nutritious diets that meet individuals’ dietary needs and allow for efficient absorption of nutrients, thereby supporting a healthy and active life. The fourth dimension, food stability, emphasizes that individuals, households, and populations must have consistent access to adequate food at all times. This access should not be compromised by economic shocks, climatic variability, or cyclical events such as seasonal food shortages (FAO, IFAD, UNICEF, WFP&WHO. (2023). Stability applies to both the availability and accessibility components of food security.

Figure5: The concept of conventional breeding, genetic engineering, and genome editing technologies.

The schematic diagram shows the steps involved during the electroporation that lead to the insertion of the exogenou s gene of interest into the plant cell.

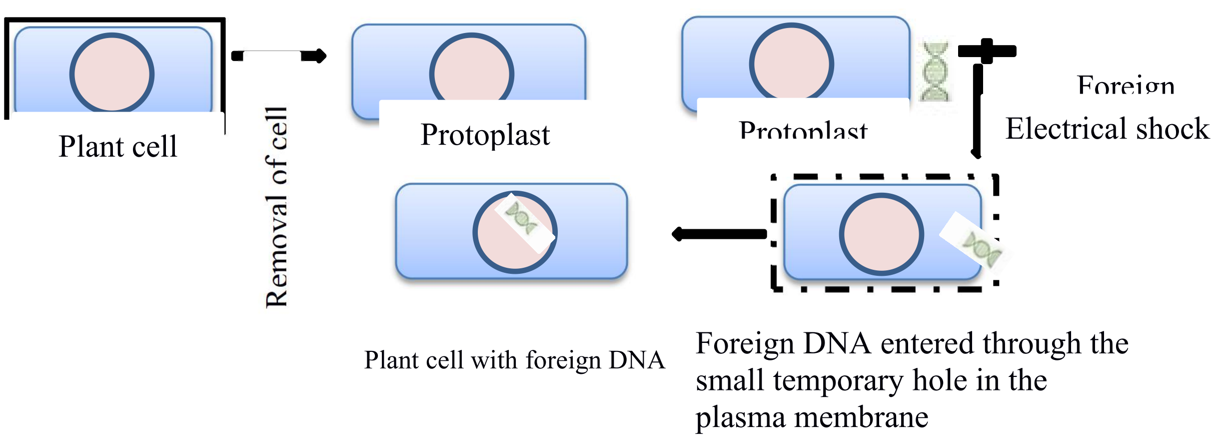
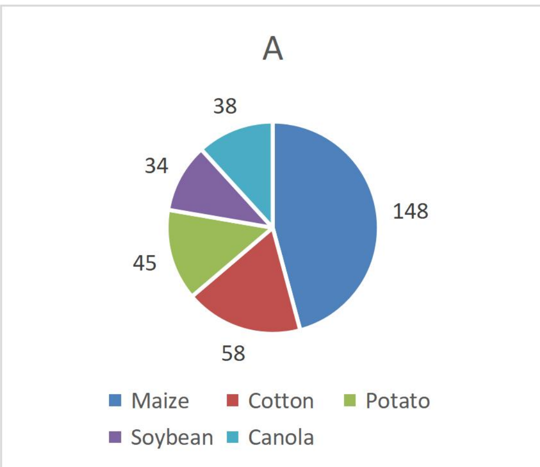
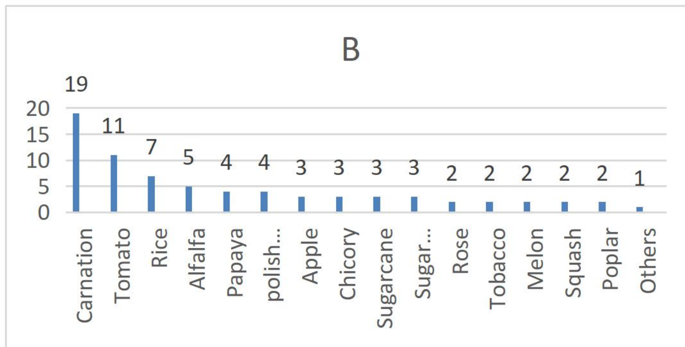


Figure 6. Electroporation method of genetic transformation of the plant?.

Over two decades since the introduction of GM corps, many countries across North America, Asia, Africa and South America have begun commercial cultivation of several GM crop varieties to enhance their food production (Table 4). However, only one event (maize) has been commercially cultivated across Europe, reflecting the continents solder captivity to Gm varieties.





Others: Petunia, Creeping banters, Plum, Sweet pepper, Eucalyptus, Bean, Flax, Eggplant and Wheat. All with one event each.

Table 3. Commercial Cultivation of Genetically Modified Crops by Country (2023)

No	Country	Cultivation Area (Million ha)	% of GM Crops in Total Crops	Major GM Crops
1	United States	74.4	45–50	Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash, potato
2	Brazil	66.7	60+	Soybean, maize, cotton
3	Argentina	23.8	60+	Soybean, maize, cotton
4	Canada	11.6	25–30	Canola, maize, soybean, sugar beet
5	India	11.9	7–8	Cotton
6	Paraguay	4.0	85	Soybean, maize, cotton
7	China	3.2	3–4	Cotton, papaya
8	Pakistan	3.0	12–15	Cotton

9	South Africa	2.7	20	Maize, soybean, cotton
10	Bolivia	1.3	30	Soybean
11	Uruguay	1.2	75–80	Soybean, maize
12	Philippines	0.9	2	Maize
13	Australia	0.7	10–15	Cotton, canola
14	Spain	0.1	0.5	Maize
15	Mexico	0.1	1	Cotton
16	Colombia	0.1	1	Maize, cotton
17	Vietnam	<0.1	<1	Maize
18	Honduras	<0.1	3	Maize
19	Chile	<0.1	<1	Maize (seed production)
20	Portugal	<0.1	10	Maize
21	Czech Republic	negligible	0	Maize
22	Slovakia	negligible	0	Maize
23	Bangladesh	<0.1	<1	Eggplant (Bt brinjal)

(Barfoot, P. (2024). ISAAA; FAO; USDA; PG Economics).

The European Union has historically adopted a cautious approach toward genetically modified (GM) technology, largely due to concerns regarding potential ecological and human health impacts. As a result, the EU has implemented strict regulatory frameworks governing the approval and use of genetically modified organisms (GMOs). Public acceptance of GM crops in Europe remains relatively low. According to available reports, only a small proportion of globally approved GM events have been authorized within the EU, primarily for food and feed use, while cultivation is limited to a few countries such as Spain and Portugal, where GM maize has been grown. It is also noteworthy that plants transformed through natural processes involving *Agrobacterium* spp. (so-called "naturally transgenic plants") may not always fall under EU GMO legislation if they do not contain recombinant DNA sequences. In contrast, in Africa, genetically modified crops are increasingly considered as a potential solution to improve food security, address macronutrient deficiencies, and enhance agricultural productivity and farmer livelihoods. (EU, EFSA, ISAAA, (2018).

13. Conclusion

One of the most significant challenges facing humanity in addressing the threats of a rapidly growing population and climate change is food security. Greater attention to agricultural research and scientific innovations in plant biotechnology provides a powerful tool to confront this challenge. Self-sufficiency in agricultural production, food security, human health and safety, and the prevention of environmental degradation are among the benefits of transgenic products. Cultivating transgenic crops that are resistant to pests and diseases can reduce the use of harmful chemical pesticides, and planting drought-tolerant crops can help mitigate and manage water scarcity. The use of transgenic products, provided they pose no risk to human life or ecosystems, can be a key solution to ensuring sufficient food quantity and quality for all. Conversely, if the safety of transgenic products is not confirmed, they could become a threat to food security.

Recommendations

Today, one of the major and fundamental challenges in the country is the shortage or low quality of food, which affects the majority of the population. Therefore, it is necessary to:

1. Establish practical domestic production sectors

2.Increase both public and private investment in research on the production of transgenic products.

3.Enact and implement appropriate regulatory laws to oversee the production of transgenic products in the country.

in this industry and conduct further scientific studies to overcome many of the existing obstacles to ensuring food security for the country's growing population.

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