Examining the Relationship between Biotech Crop Cultivation and Global Food Security Sustainable Index: A Comparative Analysis from 2012 to 2018

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Abstract. This study examines the dynamics between the cultivation of biotech plants and food protection on a global scale from 2012 to 2018 which will ensure sustainability in food. The use of facts from the worldwide food security Index (GFSI) and biotech crop cultivation regions, we analyze modifications in food security metrics alongside developments in biotech crop adoption across various international locations. Our findings reveal intriguing patterns, including extensive increases in biotech crop cultivation in Brazil and the United States, coinciding with terrific enhancements in GFSI scores in nations like Chile, Uruguay, and Argentina. Conversely, a few countries, such as Burkina Faso and Myanmar, exhibited high-quality shifts in GFSI despite stagnant biotech crop cultivation. Furthermore, simultaneous will increase or decreases in each biotech crop cultivation and GFSI rankings were observed in positive international locations, underscoring the complicated interaction between biotech crop adoption and food security effects. Moreover, we discuss the importance of considering food security at each national and household stages, highlighting the need for nuanced analyses of biotech crop contributions to general food security.

Keyword-: GMO, Food Safety, Crops, Pests, DNA, Diseases

1 Introduction

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A "genetically modified organism," or GMO for short, is an organism such as a plant, animal, or microbe that has had one or more alterations made to its genome, usually using advanced methods of genetic engineering with the goal of changing the organism's properties as shown in Fig.1.For thousands of years, selective breeding techniques have been employed by humans to alter animals such as maize, cattle, and dogs. However, recent developments in biotechnology have made it possible for scientists to directly alter the DNA of animals, plants, and microbes. By using this approach, scientists can enhance the genetic composition of creatures without undesirable features while avoiding inconsistent outcomes and undesirable qualities. In order to evaluate the health effects of genetically modified (GM) diets on animal health, the EU-funded MARLON study examined data. Upon reviewing four case studies, it was shown that there were no immunologic impacts or allergic responses when compared with non-GM feed. While insect-resistant genetically modified maize may help reduce the amount of fumonisins present in the grain, the effects on additional fungal toxins and aflatoxins are less clear. Overall, it seems unlikely that GMO-related Genetic horizontal transfer of genes will pose a health risk. Due to compositional changes brought about by genetic alterations in CS-4 crops, extra attention must be paid to the nutritional effects. There were no health indicators found, although there may be advantages to lower mycotoxins and improved nutrition [1].

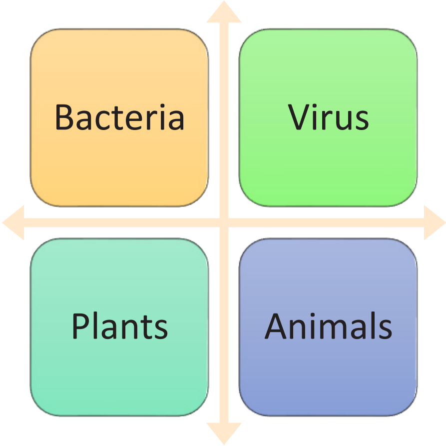

Fig. 1: Types of Genetically Modified Organisms

There are safety issues associated with genetically engineered organisms (GMOs), and handling threshold levels vary. As the number of GMOs rises, effective detection techniques are required for prompt diagnosis; DNA-based tests are well-liked because of their efficacy and ease of use [2]. With an emphasis on novelty in detection efficacy, operation procedure, and results diagnosis, this critical review explores new DNA-based techniques for effective GMO detection. Its goal is to stimulate research into more straightforward and effective detection techniques.

To develop genetically engineered organisms (GMOs), new DNA is inserted in the genetic code of an organism or plant cells. In genetically modified organisms (GMOs) like Flavr Savr tomatoes, which postpone ripening to avert rot and softness, chemicals are employed to increase yield and product sizes. As a result of modern technology protecting GM crops, agricultural productivity has risen dramatically. Medical therapy can be enhanced, food availability and quality can be improved, and air pollution can be reduced [3]. It is our belief that if they are properly implemented, they can reduce hunger worldwide and strengthen the financial system without destroying it in the process. The potential of these technologies needs to be studied carefully and risks must be assessed before they can be fully realized. In this analysis, genetically modified crops are assessed for their impact on contemporary agriculture, developing nutrient-dense staple crops for underprivileged communities and improving disease resistance.

Agrochemicals and genetically engineered crops are likely to cause stress on aquatic habitats in agricultural landscapes. This problem was only brought to light a decade ago. This study highlights the serious gaps in our understanding of GMOs in aquatic environments due to the lack of research on combinatorial stressors and the limited variety of species considered for the study on GMOs in aquatic environments. As a result of the lack of research on leached toxins, plant degradation, and the spread of aquatic habitats in [4], it argues the need for standardization of test methodologies in GMO regulation.

2 Genetic Engineering Techniques for Sustainability

Growing levels of industrialization, waste generation, and agricultural inputs are causing heavy metal pollution in waterways and crops, which poses health risks such nephrotoxicity, endocrine disruption, and mutations. In order to meet the constant need for decontamination, this review offers a single paper on phytoremediation, an environmentally benign and viable approach for metal repair on polluted locations, despite significant limitations. The study in [5] examines the principles, methods, and variables of phytoremediation, including heavy metal detoxification and plant tolerance. It promotes future research and advancement of phytoremediation techniques. The paper talks about the latest developments of botanical remediation techniques and suggests using a variety of methods along with contemporary chemical, biological, and genetic engineering instruments to effectively remove heavy metals from soil and agricultural land. In a future where people utilize linked technology to govern their lives, the economy shifts from one based on agriculture to one based on mass manufacturing, automation, and mass production. This is known as Klaus Schwab's fourth industrial revolution. The study in [6] examines the characteristics, prospects, and difficulties of the four periods of industrialization, emphasizing how they are related to one another and how manufacturing techniques have advanced. A common micronutrient malnutrition issue is iodine deficiency, which may be prevented by adding iodine to table salt. Crop bio fortification using iodine is an economical method. The study in [7] examines the biology of iodine in plants and existing bio fortification techniques, emphasizing the need for more sophisticated genetic engineering methods for specific staple crops. Naturally occurring heavy metals are being overly discharged into natural resources, which can have detrimental consequences on human well-being and aquatic biota over extended periods of exposure. This article examines how microorganisms and plants may biotransform heavy metals into less harmful forms. It also covers these resources' biological value, technological developments in the field of bioremediation, and the tolerance and degradation capabilities of these species. The work in [8] discusses heavy metal aggregator plant genomes, functional genes involved in tolerance and detoxification, and microorganisms' ability to tolerate metals. It also assesses the use of technology and bioremediation research.

3 GMO and food security

Taking aim at the inadequacies of the environmental movement, this essay examines the potential for new plant breeding technologies (NPBTs) for food security and sustainable agricultural growth. Particularly in Europe and developing nations like Africa and Asia, overregulation and erroneous public views impede the effective growth of NPBTs, calling for legislative changes and evidence-based public discourse [9]. For there to be no hunger in the world, severe poverty must be eradicated and food production must be sustainable. The food, money, and jobs that the rural poor in emerging nations depend on agriculture. High undernourishment rates are a result of low agricultural yield. Genome editing and other novel plant breeding techniques can greatly improve global food security if they are used carefully and regulated based on scientific knowledge [10]. According to [11], low-tech methods can improve food security and sustainable agriculture even though they generate poorer results. Smallholders should embrace these methods based on ecological risk containment rather than survivalist tactics Research from the Consultative Group on International Agricultural Research emphasizes the contribution of international organizations and public-sector research to the advancement of evidence-based policies that promote low- and high-tech methods tailored to specific contexts. Over 900 million people globally are undernourished or afflicted with illnesses as a result of important vitamin and mineral deficiencies, according to a 2012 FAO assessment. This shows the serious threat that the growing human population poses to food security. There is less agricultural area available due to urbanization, which makes it challenging to boost food production without compromising biodiversity and environment. The conventional dependence on resources of farmers in emerging nations presents significant issues. Raising community knowledge of food security challenges is necessary, taking into account social and ethical considerations. Although there is still disagreement among the public over genetically modified (GM) technology, it is a potential way to feed a rising population. Genetically modified technology poses concerns to human health and ethics even while it has the potential to end world poverty [12]. There has been a decrease in world hunger, with 809 million less people undernourished in the world as of the most recent FAO data, despite its broad acceptance in rich nations. But to truly comprehend the wider consequences, scientific validation is required. The study can fix productivity issues to guarantee a safe and secure food supply in the future.

4 Pest and Disease Resistance in GMO Crops

GM and genome editing can effectively manage plant pathogens in agriculture, but they must be efficacious, sustainable, and thoughtfully deployed without negative effects on plant agronomy. Allergens and poisons must be avoided by biotech crops, and expensive regulation is expensive for regional fixes. It is morally required to address plant diseases, and genetically modified crops (GM crops) are necessary to double food output by 2050. High level of input Because of soil erosion and the consequences of climate change, agriculture's advantages are dwindling. Rapid technological integration is necessary for crop growth in particular to adapt to changing circumstances and pest dynamics. With over fifty species studied, including the main crops like rice, wheat, and maize in addition to the tomato plant, genome editing in plants has demonstrated considerable promise. The application of the CRISPR/Cas9-based technology has expanded [13]. Large-scale prospective applications of genome editing include the development of resistant crops, modification of interactions, gene deletion, synthesis of artificial immunological receptors, and dissociation of defensive hormones. The potential of genome editing technology to create crop kinds resistant to pests and diseases is examined in this article, along with its benefits and expected obstacles. Pests and diseases that affect legumes include rusts, mildews, blights, and white molds; they can also be harmed by insects, viruses, bacteria, and parasitic weeds. The significance and relationships between biotic stress resistances in host plants are covered in the paper, along with the drawbacks of breeding techniques and the advantages of large-scale phenotyping, genome sequencing, and gene expression research [14].

Table 1: Agricultural Comparative Evaluation of Genome Editing Techniques and Genetically Modified Crops

Aspect	Genetically Modified (GM) Crops	Genome Editing (e.g., CRISPR/Cas9)
Pest and Disease Management	Can be engineered to resist pests and diseases, reducing the need for chemical pesticides	Enables precise alterations to make crops resistant to specific pests and diseases
Regulatory Aspects	Subject to extensive regulation, which can be costly and vary regionally	Currently faces less stringent regulation, but this could change as the technology evolves
Impact on Agronomy	Must be carefully deployed to avoid negative impacts on plant growth and soil health	Offers targeted editing with potentially less impact on non-target plant traits
Safety and Allergenicity	Must avoid introducing allergens or toxins	Precision editing aims to minimize unintended changes, reducing risk of allergens or toxins
Sustainability	Requires management to ensure sustainable practices	Promises more sustainable solutions by reducing input requirements like pesticides and fertilizers
Technological Advancement	Well-established in certain crops, but with limitations in adaptability	Rapidly advancing, offering new solutions for crops' adaptation to climate change and pests
Acceptance and Morality	Faces public skepticism and ethical debates	May face similar challenges; ethical deployment is crucial for public acceptance
Impact on Food Output	Essential for meeting growing food demands by 2050	Has the potential to significantly increase food production with less environmental impact
Applications in Crop Development	Used in major crops; limitations in fine-tuning traits	Extensively studied in various species; allows for precise trait modification
Future Prospects	Continues to evolve, but constrained by public perception and regulation	Expanding applications with potential for addressing complex agricultural challenges

Globally, insect pests cause large agricultural losses, thus in the upcoming decades, novel approaches to augment or substitute chemical pesticides will be needed to improve sustainable food supply. Crop resistance to insect pests is being improved through a variety of tactics that include plant secondary metabolism, immune, and microbiome science [15]. With the help of continuing plant breeding and genetic technology, recent advances in metabolic engineering in plant secondary chemistry promise increased plant immunity, targeted discouragement of insect pests, and the possibility to use insect pest microbiomes for insecticidal compounds.According to Table 1, genetically modified crops (GM) can be engineered to resist pests and diseases, reducing the need for chemical pesticides. However, these crops face extensive regulatory aspects and must be carefully deployed to avoid negative impacts on plant growth and soil health. Precision editing aims to minimize allergens or toxins, while sustainability requires management. Technological advancements are rapidly advancing, offering new solutions for crop adaptation to climate change and pests. Ethical deployment is crucial for public acceptance. GM crops have potential for increased food output and future prospects.

5 Reduced Pesticide Use and Conservation Tillage

The goal of sustainable agriculture is to continue producing lucrative crops while protecting the environment. It captures solar energy without affecting the quality of the environment or soil fertility. Increased energy flow and energy usage efficiency in intensive modern agriculture are necessary for it to become broadly adopted. Crop output is greatly impacted by tillage and seedbed preparation, and crop response is unpredictable. The choice of tillage is influenced by soil properties including as structure, erodibility, rooting depth, water and nutrients reserves, slope gradient, texture, and natural drainage [16]. A study conducted in [17] at eastern Austria in 1994 looked at the long-term impacts of decreased tillage by comparing the effects of mulch till and no-till on surface runoff, nutrient and pesticide losses, and soil erosion [18-21]. The study looked at mulch, no-till, and traditional soil tillage treatments at different locations. Measurements of soil erosion, surface runoff, nutrient and carbon losses were made during the growing season; data on pesticide residue losses were scarce [22]. Reduced tillage methods led to a 12–21% rise in erosion rates, but they also considerably reduced surface runoff from silt loam and poorly-drained silty clay loam soil. MT and NT decreased soil loss from silty clay loam by 38–65% and from silt loam by 70–88% and 84–93%, in comparison to conventional tillage [23]. Greater soil cover, lower flow velocities, and greater soil organic carbon levels are thought to be responsible for the decrease in soil loss following decreased tillage treatments. This leads to low rates of erosion and low nitrogen and phosphorus runoff losses; total nitrogen losses range from 13.3 to 48.1 kg ha^{-1} [24-27]. Even while runoff had higher quantities of nitrogen and phosphorus, decreased erosion rates in reduced tilled plots led to lower runoff losses of these nutrients [28]. In MT, conservation tillage decreased SOC losses by 34–86%, and in NT, by 58–89%. The study shows that in well-drained soils in central Europe, mulching without tillage increases aggregate stability, water content, and decreases soil and nutrient losses [29]. With an emphasis on yield, benefit-cost ratio, labor requirements, insect and disease infestation, and pesticide applications on five important vegetable crops, the study contrasts traditional farming practices in Nepal with the combination of conservation agriculture and integrated pest management techniques [30]. While cabbages and cauliflowers demonstrated greater yields, the enhanced alternative method for vegetable crops provided higher yields, used less work, and needed less pesticides. Along with enhancing lives and revenue, this strategy also enhanced human health and the environment [31-33]. The adoption of CA and IPM by smallholder vegetable growers can be enhanced by research on scaling alternative methods through farmer groups, government agencies, and non-governmental players. Utilizing samples from the first and second years of a four-year crop rotation cycle, a study assessed the effects of tillage treatment, crop type, and soil parameters on the ideal nitrogen rate for crop production and NUE [34]. The study discovered that, across all tillage treatments, soil compaction and overall porosity were highest on Gleysol and lowest on Stagnosol, respectively [35].

While soil cover crop residues were considerably impacted by treatment and nitrogen fertilization, grain yields, biomass, and harvest index of winter wheat and maize responded well to conservation tillage. The study in [36] discovered that as tillage treatments varied, the average nitrogen usage (NUE) dropped, with varying NUEs for winter wheat and maize. With varying tillage strategies and soil types, winter wheat yielded more grain and biomass [37-39]. The study found that the best nitrogen rates for both types of soil were N2 and N3. Regardless of tillage techniques or application rate, the most productive Gleysol had greater NUEs than Stagnosol [40].According to Table 2, Mulch Till (MT) and No-Till (NT) techniques are used in conservation agriculture and integrated pest management [41]. They reduce soil erosion, surface runoff, nutrient loss, soil organic carbon (SOC), crop yield, labor requirements, and pesticide use. MT improves aggregate stability and water content in well-drained soils, while NT reduces erosion and runoff. The impact on human health and environment is positive due to reduced chemical loss, while potential negatives include higher chemical and nutrient runoff which is form of sustainable growth [42].

Table 2: Summary of Tillage and Agricultural Practices

Aspect	**Mulch Till (MT)**	**No-Till (NT)**	**Traditional Tillage**	**Conservation Agriculture & Integrated Pest Management (CA & IPM)**
Soil Erosion	Reduced by 38–65% in silty clay loam	Reduced by 38–65% in silty clay loam; 70–88% and 84–93% in silt loam	Increased by 12–21%	Not specifically mentioned but implied to be reduced
Surface Runoff	Considerably reduced	Considerably reduced	Higher	Reduced; enhances water content and reduces soil loss
Nutrient Loss	Lower nitrogen and phosphorus runoff	Lower nitrogen and phosphorus runoff	Higher due to increased erosion	Reduced, improves nutrient retention
Soil Organic Carbon (SOC)	Decreased losses by 34–86%	Decreased losses by 58–89%	Not specified	Not directly mentioned, but practices suggest improvement
Crop Yield	Not specified	Not specified	Variable, affected by tillage and seedbed preparation	Enhanced yields in vegetables like cabbages and cauliflowers
Labor Requirements	Not specified	Not specified	Labor-intensive	Reduced labor requirements
Pesticide Use	Not specified	Not specified	Depending on crop response	Reduced needs for pesticides
Soil Properties Affected	Improved aggregate stability and water content in well-drained soils	Improved aggregate stability and water content in well-drained soils	Affected by structure, erodibility, depth, water/nutrient reserves, etc.	Enhances soil properties but specific effects not detailed
Impact on Human Health & Environment	Not directly mentioned but implied to be positive due to reduced erosion and runoff	Similar to MT, with positive implications for human health and environment due to decreased chemical loss	Potentially negative due to higher chemical and nutrient runoff	Directly positive, improving human health and environmental conditions

6 The Global Food Security Index for Nations Utilizing Genetically Modified Crops

Based at the GFSI framework, the USA, Australia, and Canada lead the index for 2018 among nations with genetically modified (GM) crop production, with Portugal, Spain, Chile, Uruguay, and Slovakia following match (refer to Table 3). Significantly, the GFSI rating for the United States experienced fluctuations during the analyzed period, while Canada's rating remained highly strong [43-46]. Conversely, Sudan, Burkina Faso, Bangladesh, and Myanmar are placed at the bottom of the index, with India and Mexico experiencing tremendous declines in ratings from 2012 to 2018. But, Myanmar, Uruguay, Colombia, and Argentina have verified amazing improvements in food security, as indicated through the GFSI [47]. Regardless of enhancements in food availability and affordability stated within the 2018 GFSI record, there was a decline in overall food satisfactory and protection scores in current years, attributed to decreased weight loss plan diversity and decrease protein first-rate [48]. The Economist emphasizes that international locations have room for development in ensuring the protection and nutritional value of food [49].

Table 3. The food security index across nations with genetically modified crops, spanning 2012 to 2018

Countries	**2012**	**2013**	**2014**	**GFSI* 2015**	**2016**	**2017**	**2018**	**Change 2012-2018 (2012=100.0)**
Argentina	65.2	65.8	65.9	68.5	63.9	69.5	66.8	112.9
Australia	87.4	84.8	86.2	88.9	86.2	89.2	86.7	172.9
Bangladesh	45.2	48.4	49.2	46.2	44.1	48.9	47.1	103.2
Bolivia	55.1	54.2	56.2	58.9	56.1	65.9	64.9	109.1
Brazil	70.2	69.1	67.8	64.3	65.9	71.9	73.2	102.9
Burkina Faso	30.2	32.1	35.9	34.1	36.9	33.1	40.1	110.2
Canada	80.3	82.8	81.9	87.7	88.8	83.1	84.0	100.7
Chile	71.2	73.2	71.5	71.9	78.3	80.9	73.2	103.2
China	65.2	62.4	67.3	68.3	69.2	66.6	69.1	102.5
Colombia	53.3	53.8	56.9	55.1	57.5	57.9	60.3	111.2
Costa Rica	67.6	65.9	63.3	70.3	70.2	69.3	72.2	106.0
Czech Republic	38.2	40.2	43.8	44.6	48.9	53.1	55.2	114.7
Eswatini (Swaziland)	-	-	-	-	-	-	-	0.0
Honduras	45.4	47.2	46.2	50.3	49.1	44.1	49.1	109.3
India	50.1	51.9	54.8	55.3	58.1	53.1	58.2	102.2
Indonesia	59.0	60.1	60.3	66.1	64.8	69.2	70.2	119.5
Mexico	70.3	78.3	69.2	65.9	64.5	68.5	70.1	99.7
Myanmar	80.9	80.3	80.1	79.3	79.5	87.2	81.4	121.2
Pakistan	48.2	46.2	41.2	44.8	47.5	50.1	49.1	110.8
Paraguay	59.2	59.3	58.4	57.1	57.4	55.3	56.3	11.5.8
Philippines	48.1	50.3	55.7	50.9	49.3	57.3	50.51	111.9
Portugal	40.8	55.3	60.3	62.4	53.2	59.2	53.9	108.4
Slovakia	60.3	60.1	63.9	62.8	65.1	68.3	69.3	98.4
South Africa	65.1	60.7	62.8	63.9	60.2	61.8	62.5	104.8
Spain	75.9	78.3	78.2	75.9	77.3	73.1	77.9	109.5
Sudan	30.1	33.6	35.8	37.4	40.2	41.7	44.2	121.8
Uruguay	64.2	67.4	68.2	66.2	69.2	70.2	61.0	105.7
The USA	89.1	81.8	80.9	81.2	88.2	85.7	76.3	96.1
Vietnam	50.1	57.3	58.3	57.1	52.1	59.2	60.1	99.4
World	60.2	55.3	65.3	73.1	65.3	65.9	53.9	102.6

Table 3 gives the comparative modifications within the area of biotech crops and the global food security Index (GFSI) amongst nations with GM crop production from 2012 to 2018

[50]. Whilst Brazil and America witnessed the most substantial increases in biotech crop cultivation, several different nations, including people with enormously excessive GFSI ratings (inclusive of Chile, Uruguay, and Argentina) [36], in addition to those with decrease GFSI rankings (like Burkina Faso and Myanmar), carried out terrific improvements in GFSI [51]. Apparently, in many of these nations, the region of GM crops remained unchanged all through the equal duration when GFSI ratings rose as shown in Fig.2. Conversely, Australia, Brazil, Paraguay, and Sudan experienced concurrent will increase in both GM crop cultivation and GFSI rankings, while the Philippines noticed declines in both values from 2012 to 2018 [52].

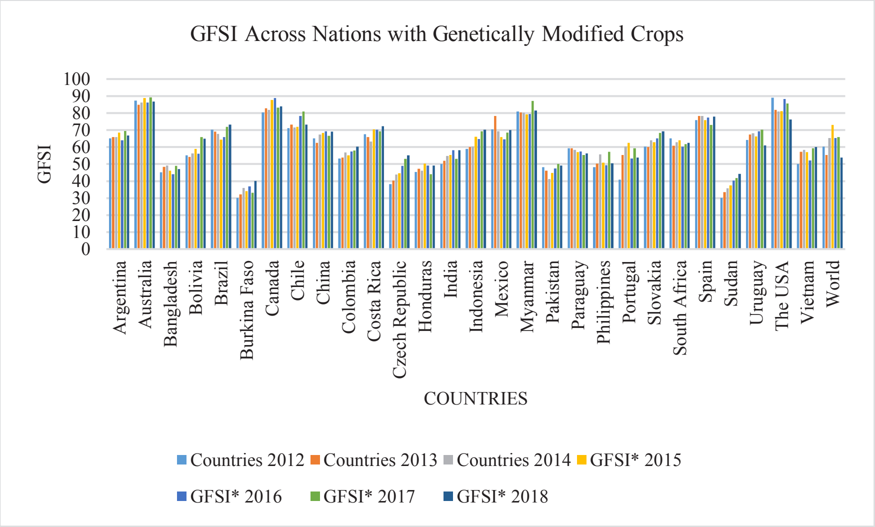

Fig. 2. GFSI across nations with genetically modified crops

Furthermore, it's important to understand that food protection varies not most effective on the national level however also at the household level, with distinct elements influencing each [53-56]. While GM plants may additionally make a contribution to expanded food production and availability, their impact on average food protection isn't guaranteed. Consequently, it is essential to assess the function of biotech crops not only in the broader context of national food protection but also in addressing household-level food protection concerns.

7 Conclusion

Our study sheds light at the complicated relationship among biotech crop cultivation and food protection effects across different nations from 2012 to 2018. At the same time as a few nations experienced massive increases in biotech crop cultivation along improvements in meals safety metrics, others noticed positive shifts in food security notwithstanding minimal changes in biotech crop adoption. These findings underscore the multifaceted nature of food security and the numerous elements influencing its attainment at both national and household tiers. Moving forward, policymakers and stakeholders must apprehend the nuanced function of biotech plants in addressing food security challenges and put into effect focused strategies to enhance common food protection while considering neighborhood contexts and household-level dynamics.

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