Partners Universal Multidisciplinary Research Journal (PUMRJ)
Volume: 01 Issue: 04 | October-November 2024 | www.pumrj.com

Policy Influence on Genetic Modification: Innovations in Enhancing Crop Nutrition

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Abstract -This research provides a graphic overview of how best to form the most influential policy on the usage of genetic modification in crop nutritional content improvement. It explains and critically describes new emerging GM traits, laws, and regulations. Crop nutritional demand has been improved worldwide due to the innovation in technology using genetic modification in agriculture. This paper looked into the cross-section between GM innovation and policy frameworks and, more importantly, their role towards crop nutritional enhancements. Thereby, a look into the existing policies that guide GM crops and nutritional standards. The paper was set to analyze opportunities and challenges that regulatory frameworks pose in the facilitation of developing and uptake of nutritionally enhanced crops. The paper depicts the dynamic interplay between technological advances, regulatory environments, and public perceptions in their shaping of the trajectory for GM crop innovations towards nutritional enhancement from an extensive review of literature, case studies, and policy analyses. It is therefore devised to ensure both safety and efficacy of food, not to mention the regulation on safety on genetic modification, where the innovation of this paper is taking place: namely, new GM crops are being developed and introduced. Other goals may be stated by regulators, but, for the initial development and for the first adoption and use of those policies in countries with such safety and proscribed technologies regulations, they largely dictate whether the agricultural inventions are safe and productive based on the evidence to be seen economically and scientifically. It is usually a process involved in enlightening regulators about the consequences of hazardous and unknown technological change. On the other hand, inadequate information or misinformation may have mixed effects. Regulatory approval, or the attainment of a contentious GM crop in an economy, might extend poorly welcomed international food aid to anti-supporting GM crops-producing countries, reduce farmer benefits, and increase development costs of beneficial changes.

Keywords: Genetic Modification (GM); Crop Nutritional Enhancement; Policy Frameworks, Regulatory Approval, Biofortification, Agricultural Innovation.

1.INTRODUCTION

There are incredible breakthroughs in genetically modified organisms. There has been special interest in crops on nutritional quality. This is so because of growing populations around the globe, demanding nutrient-enriched food. The solutions offered by GMs are quite amazing in terms of addressing food security as well as nutritional issues (Hefferon, 2015). However, all these changes are absolutely driven by policy frameworks at the national and international levels (Turnbull et al. 2021; Qaim, 2020). Policies provide the flow of genetic modification research, choices about adopting and commercializing nutritionally enhanced crops, and diffuse public concern over issues of safety and environmental impact. It is changing regulatory landscapes in most areas of operation. This calls for a need to weigh innovation against precaution, consumer protection, and ethical considerations. Successful application by genetic engineering has sparked public controversy as well as academic debate over policy responses. The variation has been wide-from government regulation, risk research of public through contribution by the private sector in developing crop varieties, to direct government risk research which would make possible the development of such varieties. The distinction and relation between research and plant varieties, and that between the research missions, is of primary importance in affecting government risk research. Another issue is the respective roles of government and industry as risk researchers. In the risk-managed environment, public research mixed with privately carried applications of genetic engineering is likely to be efficient relative to public research. Introduction of crop and animal varieties, which have been developed using genetic engineering results in changes in demands for associated research. Such changes have the potential to significantly alter the case for government participation in the research being conducted because of the difference in the variety supply system and the potential private and external returns from the research. Approaches and decisions on risk management should be reviewed if any significant change in the demand for risk research occurs. Where variety innovation leads to different products, the very tools of genetic innovation used to the generic risk management practices may have to be amended .

1.1 Overview

Genetic crop transformation, more commonly referred to as genetic engineering or biotechnology, is genetically transforming the makeup of plants in order to acquire exact sought-after traits. This simply allows for genes of rDNA to be inserted, deleted, or rearranged within the plant. Therefore, GM allows the genetic enhancement of crop plants in nutritionally more improved products, such as enhanced resistance against pests and diseases or greater tolerance towards environmental stresses such as drought or salinity (Rodríguez et al., 2022). This mainly revolves around the identification of a gene responsible for a certain characteristic in one organism then the transfer of this gene into the target crop's genome. This can be achieved by; gene splicing, CRISPR-Cas9, or any other gene editing tools. The engineered plants are then tested and developed through a series of laboratory test, greenhouse and field trials to ensure that they express the desired traits. (Zhu et al., 2020).

Despite the touted benefits, genetic crop modification has remained a controversial issue for many and at times related to public apprehension owing to various safety concerns of GMOs for human consumption, environmental impact, and ethical dilemmas (Ajoykumar et al., 2021). In response to this concern, strict regulatory frameworks have been followed in many countries across the world. Regulations in such cases demand strict testing, labeling, and provide a scope for public consultation. In the process of the genetic modification of crops, especially GM crops or crops with the insertion of a specific gene at the point of interest, this is a sort of relatively new technique and still even more precise to heighten nutritional contents. By bypassing the conventional cross-pollination, the production of hybrids, and selection of multiple genes, which are required to bring together several genes, one can produce GM plants with one or more added traits of interest. Even though GM plants have many advantages, for example, having a high content of bioavailable minerals and a mean anti-inflammatory fatty acid, public acceptance prohibits the application of this technology. This pull is largely from the slow build-up of enthusiasm in many developed countries.

This retarded further development within public perception because of public misconceptions about the merits versus risks associated with GM. Lack of knowledge on GM technology, assumed moral issues related to GM, and other belief systems like 'GM is detestable and will multiply in the environment or become a superweed like weeds are typically quoted for misleading public perception. Chelation, which improves mineral content to increase bioavailability will, unfortunately, mean increased phytates in GM crops developed with particular selectable markers. These phytates also share some potential negative effects of chelating available minerals, inducing inflammation in organs, and acting as free radical-scavenging antioxidants. Traditional marker gene excision methods are also time-consuming and labor-intensive and may introduce new DNA sequences that have been linked with health or other consumer concerns. For this reason, the industry is now testing non-GM options such as marker selection that allows GM genes to be inserted similarly in sequential series.

Recent progress in utilizing gene transfer technology, including the association of synthetic amino acids, can be used here in ancillary technologies that can overcome the current obstacles in consumer acceptance of GM crops. Specifically, the latest development is founded on the following precept: the increased nutrient content of the alb gene, the advantage of the association of synthetic amino acid auxotrophy, using the alb gene and host-specific sequences, alb gene insertion via nonsense suppression, and methods of GM labeling, such as GM containers with the association of both biochemical and biophysical marker genes containing a photoactive chemical.

1.2. International, Regional, and State Policies Governing the Production of Genetically Modified Crops and their Implication

The production of genetically modified crops is covered by a complex and ever-evolving set of rules at both national and international levels. These rules are developed to ensure safety on human health and the environment about GM crops. These equally regulate their commercialization; matters of ethical issues, social, and economic concerns. The regulatory landscape varies widely across regions, reflecting differing public attitudes, scientific approaches, and political contexts. Amongst such policies include;

International Frameworks and Guidelines

Internationally, several key organizations and agreements provide general guidelines about the regulation of GM crops. The international GM regulatory bodies include:

Cartagena Protocol on Biosafety: This is an additional agreement to the Convention on Biological Diversity (CBD) which seeks to ensure safe handling, transport, and use of LMOs including GM crops. It also has core procedures in place for risk assessment, advance informed agreement, and precautionary principle (Saeed & Mohammed, 2023).

Codex Alimentarius Commission: A Codex is established jointly by WHO and FAO in order to develop guidelines and standards of international food safety codes of practice; including GM foods. However, Codex standards lack compulsive legal status as their influence on nationals' regulations and trade arrangements (van der Meulen & Wernaart, 2019).

World Trade Organization (WTO) Agreements: The SPS Agreement of the WTO allows each country to set its level of food safety and animal and plant health standards including those concerning GM crops, however, should adhere to international standards of necessary scientific principles and not an unjustifiable discrimination on trade (Allee at al., 2017).

(i) National and Regional Regulatory Agencies & their Approaches

National and regional policies relating to GM crop production vary from country to country and region to region around the world:

United States: The United States has more lenient policy on GM crops. It is regulated through coordinated regulation by several agencies, notably the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA). The USDA, through its Animal and Plant Health Inspection Service (APHIS), supervises the introduction into, and field testing within the US, for any presence of GM crops that would not harm plant health; whereas, the EPA controls GM crops that express pesticides like Bt crop that elaborates insecticidal proteins through FIFRA and FFDCA. It safeguards against GM foods for consumption and animal feeds. The U.S. regulatory system is science-based and product-oriented rather than the process followed in the development of food (Keener, 2019; Uchtmann & Nelson, 2000).

It is based on the Plant Protection Act that regulates the introduction of genetically engineered organisms that could be hazardous as plant pests. This includes importation, interstate movement, and release into the environment. USDA-APHIS is thus argued to take part in regulating genetically engineered organisms, especially those that could be hazardous as plant pests. The EPA, however, bases its framework on the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA) which evaluates environmental safety of pesticide-producing GM crops and sets tolerance levels for pesticide residues in foods (Goldberg & Goldberg, 2003). The FDA operates under the Federal Food, Drug, and Cosmetic Act but, in policy of "substantial equivalence," the GM crop itself is usually recognized as not requiring special regulation if it is found to be substantially equivalent to its non-GM counterpart.

European Union: The most restrictive regulatory framework for GM crops exists in the EU, which is anchored on the precautionary principle to the effect that where there is no scientific proof as far as the safety of GMOs is concerned, then its release or cultivation should be strictly controlled or prohibited. This way, all GM crops have to go through a strict risk assessment by the European Food Safety Authority before one is allowed to market them (Smith et al., 2012).

Some of the regulatory frameworks governing the manufacture of GM crops among the EU member states include Directive 2001/18/EC (On the Deliberate Release of GMOs into the Environment) which provides the guidelines for the cultivation, import, and marketing of GMOs in the EU with great emphasis given to Environmental impacts, Human and animal health, and Socio-economic factors (Garcia, 2006). Another regulatory policy is Regulation (EC) No 1829/2003 on Genetically Modified Food and Feed, which regulates the authorization, labeling, and monitoring of GM food and animal feed (EFSA, 2015). The other regulatory policy is the Opt-Out Mechanism provided for in Directive (EU) 2015/412 which allows individual EU Member States to ban or restrict the cultivation of GM crops within their territories even though those crops have already been authorized at the EU level.

Australia: Examples of such bodies include the Gene Technology Regulator (GTR) and Food Standards Australia New Zealand (FSANZ). The GTR regulates, monitors and keeps under compliance GMOs to ensure that any research or production and use of GM crops is safe for people and the environment. FSANZ will approve GM foods. It tests for safety in GM foods and ensures they reach some of the very strict standards prior to their sale (Ludlow, 2019).

The GMO policies governing the body's functioning include the Gene Technology Act 2000, which established the Gene Technology Regulator (GTR) and the Office of the Gene Technology Regulator (OGTR), and the Gene Technology Regulations 2001, that provides further details on how the Gene Technology Act is implemented, outlining the contained research requirements and the release of GMOs into the environment as outlined in the risk assessment and risk management process (Thygesen, 2019).

Coexistence and State Moratoria also exist which gives individual states and territories power to regulate or even prohibit commercialized GM crop cultivation depending on market and trade considerations. For example, South Australia maintains moratoria on the commercial cultivation of GM crops, citing concerns over market access and implications for trade (Karky & Perry, 2015).

China: China is one of the important countries in the world biotechnology industry. Its regulatory system for GM crops emphasizes food security, public safety, economic interests, and technological innovation. Its regulatory framework includes: Ministry of Agriculture and Rural Affairs (MARA) that oversees GMO approvals for agricultural use; Ministry of Ecology and Environment (MEE) to ensure that protection of the environment in connection with GMOs is taken into account and the National Health Commission (NHC), which oversees issues connected with food safety associated with GMOs (Holthuis et al., 2015). These regulatory bodies operate within a legal and regulatory environment as set down by several acts, these include: Agricultural GMO Safety Administration Regulations (2001) : These regulations inform the management and testing of GMOs into existence, labeling, and production requirements in China GMO Labeling Regulations (2002): These regulations dictate proper labeling of GMO foods. Biosafety law, 2021: The act framed the legal framework through which risks associated with biotechnologies and GMOs could be managed. Specifically, it addresses GMO development, testing, and commercialization; in fact, the possible biosafety assessment and risk avoidance points must be covered (Liang et al., 2022).

South Africa: In South Africa, the production of genetically modified crops is governed by a regulatory body that encompasses; The Executive Council (EC) for Genetically Modified Organisms established under the GMO Act so as to be responsible for the approval of GMO activities including release import, export, and use of GMOs. Another regulatory authority in South Africa is the Registrar of Genetically Modified Organisms (RGMO), which oversees decisions by the EC and enforces compliance with the GMO Act (van Rijssen et al., 2013).

Among the policies that the government of South Africa enacted to regulate the production of GM crops include; The Genetically Modified Organisms Act of 1997, primarily aimed at regulating the production, importation, exportation, and use of GMOs in South Africa. The Act monitors every activity related to GMOs so as not to cause harm to the environment, human health, or biological diversity as Mayet (2004) asserts. Another legal and policy framework is the National Environmental Management Biodiversity Act of 2004, with which GMOs must comply to ensure a framework for biodiversity management and conservation; it also takes cognizance of the impact of GMOs on the environment. NEMBA complements the GMO Act in assuring not to affect the biodiversity negatively in South Africa (Britz, 2015). Foodstuffs, Cosmetics, and Disinfectants Act (FCD) equally is in place and is regulated by the Department of Health, and deals with the safety of food, including GM food. The FCD requires labeling of GM food products to inform consumers about the nature of the food they are purchasing (Mayet, 2004).

1.3. Challenges and Future Directions on the Production of Genetically Modified Crops

With progress in biotechnology, shifts in public opinion, and new scientific findings, the regulatory landscape of GM crops is changing. One of the major challenges is international standardization in favor of an open global market, modernizing regulations to accommodate emerging trends such as gene editing, and removing biotechnology disparities across the globe.

The future of GM crops will be directly related to policies on such products as the global population increases and new agriculturally threatening climate change elements pose their dangers. Core areas of governmental regulatory focus remain in striking a balance between the promise of genetic modifications in crops with the need for safety, transparency, and public trust.

1.4. Examine Policy Impacts

Along with the rise in the production and utilization of genetically modified crops, international trade issues, safety, labeling, and regulations become difficult subjects for governments in every corner of the world (Mutengwa et al., 2023). In this study, we will discuss the following:

Development of legal structures controlling the agriculture modification of genes.
The specific challenges and opportunities with which crop nutritional improvement poses.
International organizations and governmental bodies regulate genetically modified agriculture.

2. CURRENT REGULATORY FRAMEWORKS

Although there is enormous promise for raising crop yields, developing medical remedies, and resolving global issues (Wang et al., 2022).

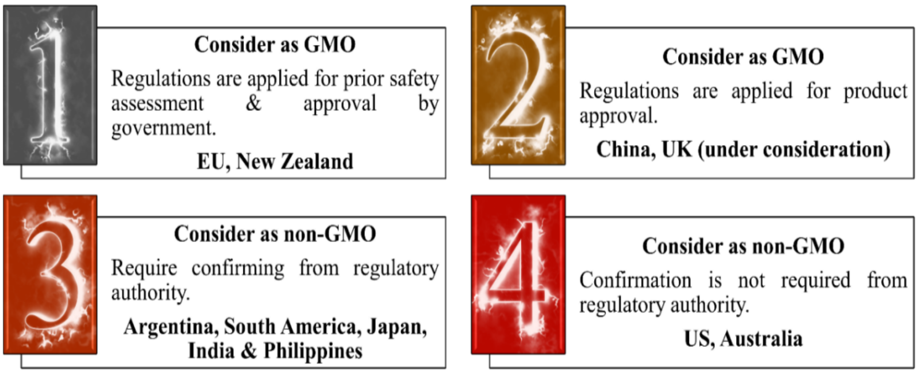

Fig -1:The figure highlights the important points and countries that apply the four approaches for GMO regulation.

Table -1: List of internationally coordinating regulatory bodies for GMO regulation.

Regulatory Body	Categorization	Regulatory objective	Member countries
International Plant Protection Convention (IPPC)	Science-based organization	Pests and pathogens (crops)	107
International Epizootics Organization (OIE)		Pests and pathogens (animals)	155
Codex Alimentarius (Codex)		Food standards and labels	165
Food and Agriculture Organization of the United Nations (FAO)		Food security programs	184
World Health Organization (WHO)		Health science and policy	191

3. FACTORS INFLUENCING POLICY FORMULATION GOVERNING THE PRODUCTION OF GM CROPS ACROSS THE GLOBE

Governance in GMOs is often a result of a multifaceted interplay involving many factors. Environmental impact and safety assessments often provide leading factors for highly standardized trial requirements, concludes Hamad et al., 2020; Hofmann et al., 2020.,

3.1 Socio-economic Factors

Issues of ethical considerations and perception by the public play great roles in influencing policy decisions and in terms of market acceptance. Many countries have also put in place procedures of public consultation, stakeholder involvement, and openness in deciding. Among the ethical issues that influence policy formulation are their impact on small-scale farmers, biodiversity, and the involvement of corporate companies in producing food.

While scientific research is the base for the legal frameworks, the economic agenda and international trade arrangements also exercise an influence over the GMO policy of other countries (Lowry et al., 2019). The strings of labelling depend on the rules of the destination country thereby, determine consumer decision and market forces. Another important factor influencing GMO development and commercialization would be the allocation of research funding and intellectual property rights. When all these factors are intertwined together, then the policymakers have to walk on a tightrope balancing the potential benefits offered versus perceived risks, which has led to different approaches being taken by other countries to regulate it.

3.2 Political factor

Public perception and political ideology both leave deep imprints on GMO restriction. Most public anxieties are based on dread of health impacts and environmental effects that are still unknown. These fears tend to be magnified by the media and campaigns led by activists(Acharya & Pal, 2020; Thangadurai et al., 2020). The political ideology further shades the way decision-makers interpret and respond to these public feelings. A conservative orientation will shade more emphasis on the economic benefit arguments, where precautionary principle will be emphasized more in the progressive view. This public opinion interference and political leaning at times cause the creation of different policies on GMOs between regions; in other cases, these policies may even contradict the science consensus of the safety of GMOs.

3.3 Trade Implication

International trade plays a prominent role in the regulation of GMOs around the world. The varied policies concerning GMOs between different countries often result in the creation of trade barriers in the exports and imports of farm produce. The main affected ones are the major agriculture producers and major exporters through the harmonization of GMO regulation to improve trade (Abobatta, 2018). Conversely, countries with more conservative laws on GMOs might be against the harmonization because of cases such as defending the economy in their market or staying abreast of the demands of the consumers. Trade treaties and international institutions, including the WTO, set GMO policies since countries negotiate to achieve their economic interests with their particular regulatory preferences (Xu, 2022).

4. GM CROPS AND THE PUBLIC PERCEPTION

Research centers also become very helpful in the development of agricultural biotechnology as a process involving multiple and complex technical procedures (Werkissa, 2022). These institutions tie up with universities or governmental bodies for fundamental research, field trials, and safety assessments.

They collaborate with farmers, industry partners, and regulatory bodies to make crop improvements in terms of pest resistance and nutritional enhancements (Bruetschy, 2019; Elizabeth et al., 2019; Kumar et al., 2019). Covering challenges from food security to climate adaptation and sustainable agriculture, they move right from genomic studies to practical applications. Public sector engagement will ensure greater accessibility to biotechnology innovations and also make sure that there will be more balance between commercial interest and social needs, though in their general perception, they vary with each other.

4.1 Farmers' Views and Perception

Modern agricultural production technology remains less accessible to small-scale farmers. This, therefore, highly serves as a hindrance to achieving the benefits of GM Crops (Mohorčich & Reese, 2019). Literate knowledge equally limits their capability of benefiting from the scientific changes that can raise their crop yield crops, and nutritional advancements, make them resilient to change in climate conditions, and improve the general productivity of agriculture.

4.2 Consumer Attitudes and Concerns

Consumers are willing to pay more for biofortified crops both for genetically modified ones and conventionally bred ones. Meta-analysis of the willingness-to-pay in general showed that customers are willing to pay anywhere from 21.6% to 23.7% extra for these nutritionally enhanced agricultural products (Ghimire et al., 2023). This high price acceptability reflects a higher awareness of health benefits associated with such micronutrient-enriched crops and market preference towards healthier crop types developed through biotechnology fulfilling their needs.

4.3 Industry Perspectives

The industry of GMO bears a very heavy burden of having a sense of responsibility to radically meet some of the worst problems the world is facing, such as the destruction of the environment and lack of food security. Indeed, these commitments speak to innovation efforts by an industry committed to not only solution development but also a roadmap toward sustainable resource management and to safe, reliable food availability for the growing population worldwide (Friedrichs et al., 2019; Sinha et al., 2023). Some other important crop changes that have been undertaken under genetic modification against insect pests' resistance top the list of GM crops globally (Table 2).

Table -2: List of commercialized genetically modified crops.

Genetically Modified Trait	Crops Improved	Commercialized events
Insect Resistance	Maize	208
	Cotton	49
	Potato	30
	Soybean	6
	Brinjal	1
	Rice	3
	Poplar	2
	Tomato	1
	Sugarcane	3
	Soybean	33

5. KEY CONCERNS ON THE PRODUCTION OF GM CROPS

Genetically modified agricultural commodities have earlier gained commercial approval for various crops, including very widely grown crops such as soy, cotton, tomatoes, potatoes, canola, and maize among others (Mohorčich & Reese, 2019; Zain et al., 2024). These approvals reflect increasing acceptance and integration of GMOs into mainstream agriculture that focuses on enhanced crop yields with improved resistance to pests and diseases thereby improving the world's food security; however, there are still some major concerns that need to be addressed during biotechnology engineering.

5.1. Environmental Concerns

There are many previous experiments that reported undesired effects resulting from new genes that were introduced into the plant genomes, mainly in GMOs (De Santis et al., 2018; Mahaffey et al., 2016). Some of the secondary effects can result in a change in the growth and development process of the plants and may interact differently with the environment. Other secondary effects may also relate to changes in biodiversity or the ecosystem (Islam et al., 2020). The results of the studies above highlight the complexity and uncertainty surrounding genetic alterations and form the basis of why there is a necessity to undertake high-risk assessments and long-term monitoring to ensure that GMO crops are safe for human consumption and the environment.

5.2. Ethical Considerations

Further research is in order on the ethical dimension of biofortification to be able to understand the actual impact of biofortification on issues of autonomy, liberty, and food justice, in particular, on production practices and diets (Li et al., 2023; Sohi et al., 2023). Importantly, this study will allow research into how biofortification might impact the ability of individuals to choose the food that they grow and eat as well as how it will exacerbate broader social and economic inequalities. Then, it becomes prudent, while deepening the investigation of such ethical issues, to make sure that the formulation and implementation of biofortification programs shall give fair respect and enhancement for equality and individual liberties (Przezbórska-Skobiej & Siemiński, 2020).

6. FUTURE TRENDS AND POLICY RECOMMENDATIONS

To accomplish this, it should extend these biotechnological breakthroughs much further, capturing much more thoroughly part of the biodiversity of plants already existing (Sánchez-Paniagua López et al., 2018). This kind of range would allow for the creation of crops much more suitable for challenges within the global system, reasserting the necessity of international cooperation on GMO law.

6.1 Emerging Innovations

The speed at which biotechnology has evolved, incorporating techniques that have allowed plant breeders to fast-forward enhancements of crops with specific sequence alterations, tells the truth about why global cooperation on GMO legislation is so important(De Santis et al., 2018).

6.2 Strengthening International Collaboration

GMOs are a matter of significant international concern in our increasingly interconnected world; environmental sustainability challenges, food security (Seralini, 2020), and biotechnology advancements are critical issues facing the world today. Countries need to come together and work to ensure complete regulation of the dangers and benefits of GMOs in order to protect our common environment and supply food for our future people. Only through cooperation will we tackle these complex and fluid issues (Sohi et al., 2023).

6.3 Balancing the Interests of Stakeholders

GMOs are a matter of significant international concern in our increasingly interconnected world; environmental sustainability challenges, food security (Seralini, 2020), and biotechnology advancements are critical issues facing the world today. Countries need to come together and work to ensure complete regulation of the dangers and benefits of GMOs in order to protect our common environment and supply food for our future people. Only through cooperation will we tackle these complex and fluid issues (Sohi et al., 2023).

7. CONCLUSION

Crop nutrient requirements keep on increasing in an accelerating rate as the World's population also increases. Climate change, environmental changes and decline in arable land have led to decline in crops rich in nutrients, reduction in yields and poor resistance to pests and diseases. Domestic agricultural policy can, and often does, influence the uptake and impact of new crop technologies. Some policies might explicitly favor the search for innovative varieties of higher nutritional value (such as those being produced by new biofortification methods), while others may help more indirectly by not discriminating against more nutritious GM varieties relative to conventionally bred varieties. This would drive further crop development and deployment of nutritionally important genetically modified crops and significantly increase the market demand and impact on nutrition and health outcomes. Genetically enhanced crops will require putting together an effective governance arrangement-which would include collective rules, official agencies, and formal and informal rules and norms-that allows the new trait to be transferred, incorporated into plant reproductive parts, and ultimately developed into new varieties for commercial use. In any case, it has always been a breakthrough double-edged sword, requiring craft, public acceptance of the novel trait, and institutional accommodation to minimize the trade-offs associated with the introduction of genetically modified strains. The actualization of opportunities by the new generation of transgenic crops demands new methods involving the introduction of new genes be aligned with differential learning, private governance, and institutional adaptation to realize positive novel trait influence forms and minimize potential negative influence forms encountered. GMO crop rich nutrients need to be advocated through proper enlightening of the farmers to change their perceptions about GMO crops. Countries with a strict regulatory framework to curb them and allocate more resources on GMO crops nutrition research funds in coming up with crop innovation which shall be adopted. More research studies will have to be carried on long-term risk assessment, impact on the environment and human health risk, nutritional quality and improvement to sustainability.

DISCLAIMER (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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