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Role Of Crop Biotechnologies In Global Food Security: A Survey

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Abstract: Today, we stand at the forefront of a thrilling era in biotechnology, particularly in crop biotechnology, with the potential to revolutionise agricultural output and ensure an abundance of nutrients for our rapidly growing population. The market for genetically modified crops is on the brink of explosive growth, promising resilient, high-yielding, and nutrient-rich crops that will transform how we cultivate food. The potential of genetic engineering is not just promising; it is inspiring. We envision creating new plants with extraordinary traits such as amplified productivity, exceptional quality, disease resistance, and adaptability to diverse environmental conditions. Public perception, government policies, and scientific evidence influence attitudes toward biotechnology and genetically modified foods, crucial to ensuring safe and sustainable food security. Additionally, stringent biosafety regulations are essential to ensuring the safety of biotech crops for consumption and the environment. By expediting approvals for these crops, we are paving the way for a thriving and sustainable future in agriculture.

Index Terms: Crop biotechnology, food security, GMOs, sustainability

I. Introduction

The idea of 'food security' has been understood in various ways throughout different periods and situations. One of the most widely accepted definitions comes from the 1996 World Food Summit, which defines food security as ensuring that everyone has consistent access to safe, sufficient, and nourishing food to meet their dietary needs and maintain a healthy, active lifestyle (Pinstrup-Andersen, 2009). Global food security is facing a looming threat due to population growth, climate change, limited arable land, and the need to improve agricultural productivity to meet the needs of a growing global population. These challenges are not just hypothetical scenarios but urgent issues that demand immediate attention, sustainable practices, technological innovations, and efficient resource management to secure a better future for everyone. The projected number of people experiencing food insecurity in 2023 is 345 million, up from 135 million before the pandemic (Deloitte). This significant increase in the number of people facing food insecurity, mainly due to the economic impacts of the pandemic and other factors, underscores the urgent need for innovative solutions in agriculture and biotechnology. We must take action now to address these pressing issues. The role of biotechnology in tackling these urgent food security issues cannot be overstated. Biotechnology, particularly crop biotechnology, is essential in providing innovative solutions that greatly enhance agricultural production and ensure nutrient availability for a large population. This potential

provides hope in these challenges, demonstrating that a secure future is not just a dream but an attainable reality. Ensuring food security necessitates consistent access to a safe and nutritious food supply that meets people's dietary requirements and enables them to maintain healthy and active lifestyles. (McCarthy, U., Uysal, I., Badia-Melis, R., Mercier, S., O'Donnell, C., & Ktenioudaki, A. 2018).

a) Advancements in Biotechnology for Enhanced Crop Production and Food Security

The application of scientific engineering principles in the development and enhancement of crops has emerged as a promising approach to addressing global nutritional security challenges. By utilising biotechnology techniques such as genetic engineering, researchers can improve desired crop traits, including yield, pest resistance, and tolerance to environmental stresses. The market for genetically modified crops is expected to witness substantial growth in the coming years, projected to reach $29.87 billion by 2028 at a compound annual growth rate of 6.1% (thebusinessresearchcompany.com). This technology offers the potential to cultivate more resilient, productive, and nutritious crops, ultimately contributing to increased food production and sustainability in the face of population growth and climate change-related challenges (Wang, X., Kang, M., Sun, H., de Reffye, P., & Wang, F. Y. 2022). Biotechnology is not only a promising tool but a crucial one, currently being applied across various facets of agriculture, including crop monitoring, irrigation management, disease detection, fertilisation techniques, automation of tasks, image analysis, data interpretation, yield prediction, supply chain optimisation, implementation of decision support systems (DSS), weed management, and resource utilisation optimisation. This technology ensures food security by enhancing crop yields through multi-temporal remote sensing (RS) methods, enabling precise identification of different crop characteristics, monitoring of land cover changes, assessment of soil organic matter fluctuations, prediction of soil moisture levels, modelling of plant biomass, and comprehensive monitoring of crop growth (Ahmad, A., Liew, A. X., Venturini, F., Kalogeras, A., Candiani, A., Di Benedetto, G., ... & Martos, V. 2024). This assures us that biotechnology is a reliable and effective tool for ensuring food security by enhancing crop yields.

b) Impact of Modern Biotechnology on Agriculture

Modern biotechnology represents a technologically advanced evolution of traditional breeding methods, capable of rapidly developing innovative products such as plants and animals with enhanced fertility characteristics (Tan, C., Kalhoro, M. T., Faqir, Y., Ma, J., Osei, M. D., & Khaliq, G. 2022). In this context, modern biotechnology denotes a technologically superior form of conventional agricultural practices capable of producing innovative products concisely, surpassing traditional farming practices' capabilities and revolutionising agriculture (Bonciu, E. 2023). The primary outcome of biological evolution is genetic engineering, which presents boundless opportunities for the direct manipulation of genetic material, carrying significant economic and social implications that are among the most promising. Genetic engineering, also known as recombinant DNA techniques or genetic modification/transformation, involves altering an organism's genetic composition. One of the techniques used in genetic engineering is transgenesis, which introduces a foreign gene into an organism's genome (Bonciu, 2023). The procedure allows for the creation of new plants with improved productivity, quality, disease resistance, and the ability to withstand unfavourable weather conditions. The resistance of agricultural plants to diseases is often a complex genetic trait. Approximately 11.72 million hectares of genetically engineered crops were seeded in Canada in 2023, an increase from about 11.24 million hectares the previous year (Statista).

c) Impact of AI on Agricultural Sustainability

The use of AI in biotechnology companies extends beyond mere application; it involves the creation of autonomous robots that can carry out essential agricultural tasks, such as crop harvesting, at a much faster pace than human labour. This precise application of plant protection agents for pest and disease control supports sustainability in traditional agricultural systems. By employing real-time imaging of plant disorders and utilising Unmanned Aerial Systems (UAS) and Artificial Intelligence (AI), targeted and automated spraying of pesticides and fertilisers with high precision becomes possible, reducing contamination risks for crops, animals, humans, and other environmental resources. AI, through its ability to process large amounts of data and make decisions

based on that data, plays a pivotal role in identifying new crop phenotypes that demonstrate enhanced resource efficiency and resilience to changing climate conditions, offering potential solutions for food security by adapting agricultural practices to a shifting climate. This reassures us about the adaptability of farming practices in the face of climate change. (Holzinger, A., Keiblinger, K., Holub, P., Zatloukal, K., & Müller, H. 2023).

d) Drone Technology and Machine Learning in Biotechnology

Looking into the future, we envision a world where digital technology and deep learning algorithms seamlessly integrate into agriculture, allowing drone data analysis to monitor crop and soil health. The anticipated global drone industry expansion is expected to realise a significant milestone, reaching $54 billion by 2025, with India expected to capture a significant share, potentially reaching $4.2 billion and expanding to $23 billion by 2030, as stated in the EY-FICCI report 'Making India the Drone Hub of the World' (Economic Times). With their ability to track and predict environmental changes, such as weather fluctuations affecting crop yield, machine learning algorithms are set to transform intelligent agriculture. Biotechnology in agriculture has the potential to provide nutrition supply by adjusting agricultural practices to a shifting climate, helping identify resilient crops that can withstand environmental fluctuations and extremes such as droughts, and ensuring crop yields can sustain abiotic stresses that significantly impact productivity. The potential of biotechnology bolsters this confidence in the future of food security. (Javaid, M., Haleem, A., Khan, I. H., & Suman, R. 2023).

The literature review provides a comprehensive overview of a study's research methods, key findings, and insightful discussion on the implications of digital technology and deep learning algorithms in agriculture and food security. It delves into the impact of biotechnology on agriculture, consumer attitudes towards genetically modified foods, and policy implications. Moreover, it explores the geographical distribution of crop biotechnology and its impact on food insecurity, evaluates the relationship between literature themes and official definitions of food safety, and discusses public perceptions and education regarding biotechnology and genetic engineering. The passage sparks a thoughtful debate, draws multiple conclusions, and encourages further exploration and discussion.

II. Literature review

"The term 'biotechnology' was initially coined by Karl Erkey, a Hungarian agricultural economist and engineer, a century ago. He described it as producing items from natural resources with the help of living organisms.(Amarakoon et al., 2017; Bud, 1994) (Yeung, A. W. K., Tzvetkov, N. T., Gupta, V. K., Gupta, S. C., Orive, G., Bonn, G. K., ... & Atanasov, A. G. 2019). The start of the Green Revolution was during the 1960s and 1970s, which was a time of incredible advancements in agriculture. During this time, farmers of all scales embraced new varieties of food crops developed through conventional breeding rather than genetic modification (Harfouche, A. L., Petousi, V., Meilan, R., Sweet, J., Twardowski, T., & Altman, A. 2021). From the mid-1980s onward, biotechnology increased prominence in research across various sectors (Kennedy, 1991). It embodies a distinctive biological approach employed across diverse industries. Genetically modified (GM) foods represent another facet rooted in biotechnology, significantly impacting our daily lives (Yeung, A. W. K., Tzvetkov, N. T., Gupta, V. K., Gupta, S. C., Orive, G., Bonn, G. K., ... & Atanasov, A. G. 2019). Although a 2002 survey revealed that most consumers held a negative view of GM foods, perspectives have changed (Magnusson, M. K., & Hursti, U. K. K. (2002). By 2018, genetically modified (GM) crop varieties were cultivated in 26 countries globally, indicating the growing influence of biotechnology in agriculture (Harfouche, A. L., Petousi, V., Meilan, R., Sweet, J., Twardowski, T., & Altman, A. 2021).

a) Consumer Attitudes and Policy Implications of Genetically Modified Food

Consumers are expressing concerns about genetically modified (GM) food, and their choices regarding consumption are crucial for governments and agri-business firms when they formulate policies and strategies. The level of knowledge consumers have significantly shaped their attitudes towards purchasing and consuming GM food. In less industrialised nations, there is a favourable view of genetically modified foods due to the increased need for food and nutrition. (Sendhil, R., Nyika, J., Yadav, S., Mackolil, J., Workie, E., Ragupathy, R., & Ramasundaram, P. 2022). The decisions made by governments to allow or ban the growth of GM crops have a significant impact on public approval. Similarly, public support grows when the potential benefits of the technology are clearly explained, and consumption increases with price discounts. A positive media influence enhances people's trust in the government and belief in science. Genetically modified food can significantly improve food security and help alleviate undernutrition. Therefore, addressing the challenges associated with regulatory and consumer acceptance of GM food should be a top priority. Consumer awareness about GM foods, supported by scientific evidence promoting these products, needs to be heightened. Furthermore, governments should formulate and enforce policies to ensure public safety while promoting beneficial GM food products that can help address hunger and nutrition issues (Sendhil, R., Nyika, J., Yadav, S., Mackolil, J., Rama Prashat, P. G., Workie, E., ... & Ramasundaram, P. 2021).

b) Enhancing Agriculture with Biotechnology

Adopting biotechnological methods in agriculture has immense potential to enhance food availability and security. These techniques can significantly increase yields, particularly in vital food crops, by enhancing crop resistance to pathogens, adverse weather conditions, and soil constraints. They also boost adaptability to diverse climates, a crucial factor given the challenges of climate change. By developing plants with heightened resilience to both biotic and abiotic stresses, farmers can achieve higher yields while reducing reliance on chemicals and water (Bigini, V., Camerlengo, F., Botticella, E., Sestili, F., & Savatin, D. V. 2021). The goal is to boost crop productivity while responsibly using land and water resources, which is achieved by integrating biotechnological tools and advanced high-throughput phenotyping techniques (De Ollas, C., Morillón, R., Fotopoulos, V., Puértolas, J., Ollitrault, P., Gómez-Cadenas, A., & Arbona, V. 2019). Plant biotechnology and agriculture advancement rely on effectively integrating and applying various scientific disciplines, such as phytovitroculture, cell biology, biochemistry, and informatics. These advancements provide innovative solutions for enhancing food security. The primary objective of the revolution in plant genetic transformation is to combine new molecular tools, screening technologies, and economic assessments. While transgenesis emerges as a valuable tool for improving food security and mitigating poverty, it is essential to note that using transgenic crops is not without risks and ethical concerns. Novel genetic modification techniques have been developed, including TALENs, zinc finger nucleases, and CRISPR/Cas9, known as gene editing or site-directed mutagenesis. Millions of farmers worldwide continue to opt for transgenic crops due to their socio-economic and environmental advantages and crucial role in addressing food security concerns (Zhang, C. 2023). Transgenic plants play a significant role in enhancing food security by boosting productivity, promoting biodiversity conservation, diminishing greenhouse gas emissions, and reducing the environmental impact of pesticides (Montagu, M. V. 2019).

c) Potential of Microbial Bioproducts in Agriculture and Biotechnology

The use of abundant microbial bioproducts as growth enhancers in agricultural biotechnology has the potential to replace agrochemicals and increase crop yield. The naturally occurring microbiota in soil or through biofertilisers has emerged as a promising approach to sustaining intensive agricultural production by improving soil quality (Zaidi, A., Ahmad, E., Khan, M. S., Saif, S., & Rizvi, A. (2015). Certain beneficial bacteria, known as plant growth-promoting rhizobacteria (PGPR), play a constructive role in enhancing plant growth by promoting root system development or bolstering plant resilience against various environmental stresses,

including those induced by nutritional deficiencies (Glick, B. R. 2012). Improvements in root structure, growth, and water absorption have effectively enhanced drought tolerance in various crops, thereby supporting crop productivity. However, the diseases caused by these organisms in plants pose a substantial and persistent threat to global food sources. Biotechnological methods for creating disease-resistant plants aim to produce economically valuable crops using elite genetically modified (GM) varieties. In addition, the impact of biotechnology and genetic engineering (GE) on various aspects of life is widely debated. Some argue that these technologies pose significant risks to wildlife, humans, and the environment, citing the potential long-term impacts of genetically modified organisms (GMOs) on healthcare and environmental safety. On the other hand, proponents assert that the benefits of biotechnology and GE, such as improved food safety, farmer income, ecological health, and the sustainability of food supply, far outweigh the risks (Areche, F., Gondal, A., Sumarriva-Bustinza, L., Zela-Payi, N., Sumarriva-Hustinza, I., Oscanoa-León, R., ... & Gamarra, F. B. L. 2023).

d) Regulatory Landscape and Public Perception of Genetically Modified Crops

Regarding regulations, India ranks as the fourth biggest grower of genetically modified crops worldwide, as reported by the International Service for the Acquisition of Agri-biotech Application. (ISAAA) (Adlak, T., Tiwari, S., Tripathi, M. K., Gupta, N., Sahu, V. K., Bhawar, P., & Kandalkar, V. S. 2019). The United States ensures the safety of GMOs for human, plant, and animal health through collaborative efforts by the FDA, EPA, and USDA (Nutrition, 2020). Similarly, in Bangladesh, the Department of Environment, Government of Bangladesh, oversees and enforces the biosafety regulatory process for genetically engineered plants (Palit, P., Chowdhury, F. T., & Khan, H. 2021).

The increasing unease about the safety of genetically modified crops has sparked a pressing need for innovative technologies. It approaches enhancing plant resilience to stress and optimising the use of agrochemicals to ensure food security is safe and sustainable. As awareness of biotechnology grows, its positive impact on humanity becomes increasingly apparent. Factors such as public perception and acceptance of GMOs, government regulations, and farmers' adoption of biotechnological advancements are pivotal in this process. Research also indicates that acceptance of GMOs rises with higher individual knowledge levels, suggesting that education and awareness are crucial in shaping public attitudes toward biotechnology and genetic engineering. (Gbashi, S., Adebo, O., Adebiyi, J. A., Targuma, S., Tebele, S., Areo, O. M., … Njobeh, P. 2021).

III. Research problem

The research paper discusses the potential risks of GMO crops and their impact on the ecosystem. It highlights the importance of sustainable crop biotechnologies in promoting global food security.

IV. Research objective

1. Investigate the impact of crop biotechnology on food security.
2. Analyse the effects of consumer awareness of GMO crops on government policies for genetically modified plants.
3. Assess new plant breeding and biotechnological innovations for enhancing global food security.

V. Hypothesis

H1: Innovative biotechnologies for crop cultivation ensure global food security.
H2: The Indian government's policies aim to tackle and reduce the possible dangers linked to the spread of genetically modified crops.

VI. Research Methodology

The advancement of crop biotechnology has sparked growing interest in, and at times, misconceptions about genetically modified organisms (GMOs) among consumers. It is imperative to provide consumers with accurate information as their awareness deepens. This understanding can influence government policies, promoting the cultivation of safe GM crops and enhancing sustainable food security. Giving priority to consumer education and safety regarding genetically modified (GM) crops is essential. Government policies should support the responsible development and use of GM crops, maintaining a balance between innovation and safety.

Supportive government policies and up-to-date consumer attitudes are crucial for maximizing the potential benefits of these technologies and ensuring their positive impact on sustainable food security. Misconceptions about GM crops often arise from insufficient or misleading information, leading consumers to view GM crops as unsafe or unnatural. This lack of awareness can breed apprehension and resistance, perpetuating misunderstandings that impede the integration of biotechnological advancements. It is essential to recognize that GM crops can revolutionize agriculture and ensure food security for future generations.

For my analysis, I used archived data from Statista, Deloitte, and McKinsey, which are highly relevant to the topic. By conducting a descriptive analysis, I emphasised the objectives and implications of the connection between crop biotechnology and global food security, a topic of great relevance to our audience. The study's findings were presented through a comprehensive examination of scholarly articles from Scopus, Web of Science, and Google Scholar, further enhancing the relevance of the research.

VII. Research Framework

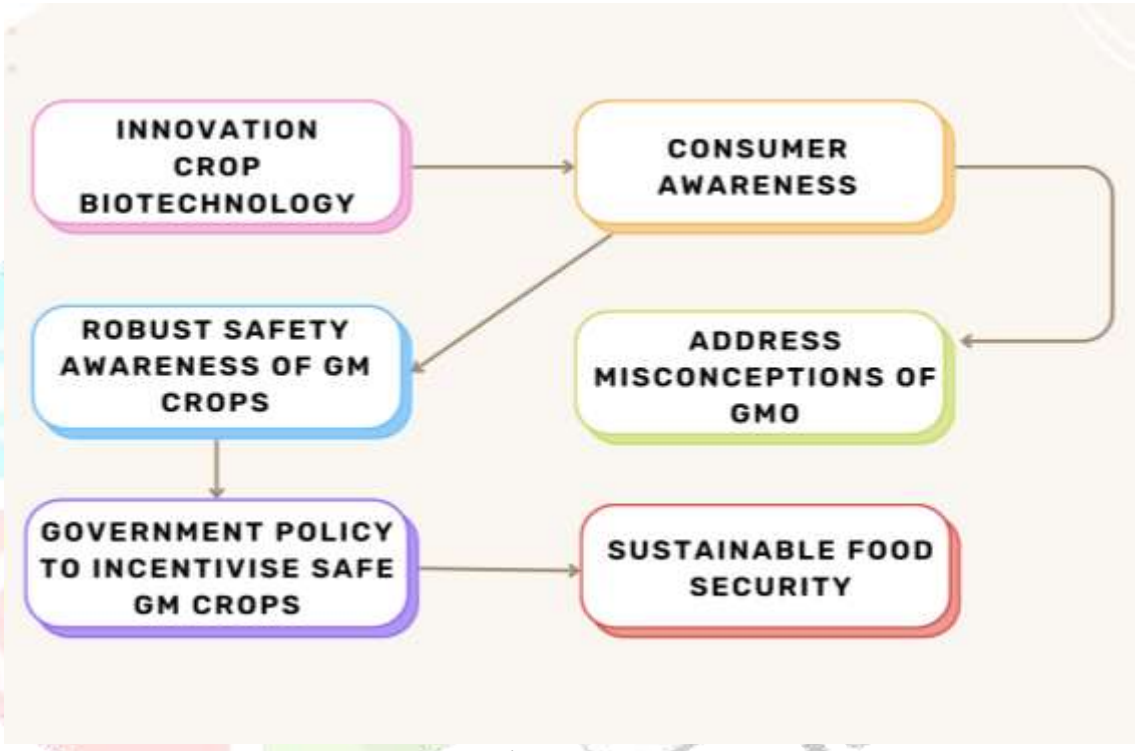

Figure 1

VIII. Results and discussions

- Biotechnology advancements have significantly improved crop breeding programs and enabled the development of genetically modified crops and products worldwide.
- Strict adherence to regulations is essential to ensure the sustainable use of biotechnology products.
- Collaborative efforts in agriculture have tripled agricultural production over the past 50 years due to expanding arable land, technological progress (such as GMOs), and rapid population growth.
- Managing biotechnology risks involves increasing public knowledge and providing individuals with information about the safe use of biotechnology.
- As depicted in Figure 1, policymakers must comprehend and honour consumer perceptions of GM foods.
- The awareness and trust of consumers in government organisations significantly influence attitudes toward GM foods.
- Public education and awareness campaigns about GMOs, the National Biosafety Framework (NBF), and government institutions help address challenges associated with misinformation and lack of trust.
- The public reception of GM foods heavily influences the acceptance of genetically modified (GM) products in developed nations.

- As shown in Figure 1, the public's attitude towards genetically modified (GM) foods differs from country to country. This emphasises the significance of comprehending and honouring public feelings about genetically modified organisms and consumer viewpoints on GM products.
- Since introducing biotech crops in 1996, countries have implemented biosafety regulations to ensure their safety for consumption and the environment.
- Streamlining approvals for farmers, consumers, and technology developers is crucial, as biotech crops offer economic advantages that support additional research and adoption, promising a prosperous and sustainable future for agriculture.

IX. Conclusion

The impact of agriculture on the economies of countries that rely on it is immense. Agriculture contributes approximately 30% to the GDP of these nations and employs about 50% of their workforce, particularly in developing nations. The livelihoods of around two billion individuals are supported by roughly 500 million small farms in developing countries. Urgent attention is required to address these issues, especially considering that three-quarters of the world's impoverished population resides in rural areas closely connected to agriculture. Carefully assess the outcomes of GM technology before implementing it on a large scale, particularly in developing countries, to tackle food insecurity effectively.

Additionally, we must recognise the potential of organic farming in bolstering food security. Public awareness about GM and organic farming methods is vital for enabling consumers to understand their quality and health benefits. Consumer awareness and preferences are crucial in enhancing agricultural products for sustainable and responsible food security.

X. Future scope

We can expect significant advancements in biosensor technology in the coming years. Integrated systems, a wide variety of analytes, microfluidics, and a focus on whole-cell and tissue biosensors will drive the progress. These advancements will be invaluable in large-scale food processing industries, export units, wholesalers, and commercial sites, allowing for easy and rapid quality assessment and task management. Furthermore, microfluidic technology will play a crucial role in the progress of biosensors by offering benefits such as increased processing capacity, reduced sample and reagent volume, improved detection sensitivity, and a unified platform for both sampling and detection.

The advancement of sustainable agriculture will depend not only on biosensor technology but also on a range of advanced technologies, including UAVs, remote and ground sensors, communication technologies, and cloud computing. The integration of these technologies is essential for crop production and enhancement. Implementing advanced and innovative technologies like the IoT is not just an option but a crucial necessity.

These advanced technologies can improve farmers' agricultural resources and methods, fostering sustainable agriculture. Moreover, the anticipated progress in agrinanotechnology is expected to support precision farming, facilitating the efficient utilisation of natural resources in agriculture. Nanotechnology offers a solution to enhance productivity and is essential for sustainable agriculture, especially in economies heavily reliant on agriculture, such as India.

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