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OVERVIEW ARTICLE



An overview on the impact of genetically engineered organisms on crop yield and safety

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ABSTRACT

Genetically Engineered Organisms (GEOs) have ushered in a new era in agriculture, revolutionizing crop yield and safety through techniques like transgenic modification and genome editing. This review delves into the profound impact of GEOs on agricultural landscapes, elucidating their role in enhancing crop traits, and bolstering resistance to pests, diseases, and adverse environmental conditions, thereby ensuring food security for a burgeoning global population. However, amidst these advancements, persistent concerns regarding GEOs' environmental and health ramifications persist. The review critically examines potential unintended consequences within ecosystems and addresses human health implications, particularly allergenicity. Furthermore, it scrutinizes existing regulatory frameworks and the pivotal role of public perception in shaping the trajectory of GEOs. While emphasizing the intricate interplay between genetic engineering and crop production, the review advocates for continued research and informed decision-making to harness the benefits of GEOs while mitigating potential risks. Additionally, it underscores the significance of enhancing science communication and regulatory measures to address ethical concerns and combat misinformation. With advancements in precision gene-integration technologies and emerging research in biofortification and stress tolerance, GEOs are promising to enhance commercial agriculture's productivity and profitability. However, achieving this potential necessitates proactive measures such as improved regulation, risk mitigation strategies, and enhanced communication with stakeholders to ensure GEOs' responsible and sustainable integration into agricultural systems.

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INTRODUCTION

A genetically modified organism (GMO) is an organism whose genetic material has been modified through genetic engineering methods, and the precise definition of a GMO and the criteria for genetic engineering can vary. Still, it often involves modifying an organism in ways that do not naturally occur through mating or natural recombination. Creating a genetically modified organism is a multi-stage process that requires genetic engineers to first identify the gene they want to incorporate into the

host organism, along with other genetic components like a promoter and terminator region, and frequently a selectable marker (WHO, 2023). Several methods are available for integrating the isolated gene into the host's genome, and recent advances, such as the use of genome editing techniques like CRISPR, have significantly simplified the production of GMOs. The yield-enhancing capabilities of GEOs are a primary focus of this review. Genetic modifications have allowed for increased resistance to pests, diseases, and environmental stressors, as well as improved crop quality and yield potential. Our analysis

will draw upon an array of studies, including the pioneering work of Butron *et al.* (2017) on genetically modified maize for insect resistance and the comprehensive meta-analysis on the yield impacts of genetically modified crops (Klümper and Qaim, 2014; Bhandari and Yogi, 2023). These studies represent just a fraction of the extensive body of research that will be synthesized in this review. Furthermore, the safety aspects associated with GEOs are of paramount importance. We will explore the measures implemented to ensure the environmental and health safety of genetically modified organisms. This includes an examination of rigorous regulatory frameworks and biosafety protocols. Studies like Domingo and Bordonaba's (2011) comprehensive review of the safety of genetically modified foods and the guidelines provided by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) will guide our discussion in this domain.

METHODOLOGY

The systematic and comprehensive methodology employed for this review on the effects of genetically engineered organisms (GEOs) on crop yield and safety involves an extensive literature search in academic databases, scientific journals, and reputable sources until December 2023. The search will be guided by relevant keywords such as "genetically engineered crops," "GEOs," "crop yield," and "safety" to pinpoint peer-reviewed articles and research papers. Strict inclusion criteria will be applied to screen the sources for relevance, ensuring that only eligible studies are included. Data extraction will encompass the collection of data about the types of GE crops, experimental techniques, and findings concerning crop yield and safety. The subsequent synthesis of these findings will entail the categorization and analysis of data to unveil patterns, commonalities, and distinctions across various studies. A critical evaluation of the selected research's methodology and quality will be undertaken to gauge the validity of the findings. In sum, this review aspires to furnish an objective and thorough scrutiny of existing literature on the subject, offering insights into the impact of GEOs on crop yield and safety.

IMPACT ON CROP YIELD

In 2014, the most extensive review to date concluded that the impact of GM crops on agriculture was positive. This comprehensive meta-analysis encompassed all publicly available English-language assessments of the agronomic and economic effects from 1995 to March 2014, focusing on three major GM crops: soybean, maize, and cotton. The study disclosed that herbicide-tolerant crops led to decreased production costs. At the same time, insect-resistant varieties exhibited an offset between reduced pesticide use and higher seed prices, ultimately resulting in similar overall production costs (Chilton, 2019). Yields witnessed a remarkable 9% increase for herbicide-tolerant crops and an even more substantial 25% boost for insect-resistant varieties. Farmers who embraced GM crops

reported a remarkable 69% surge in profits compared to those who adhered to conventional farming practices. Importantly, the review found that GM crops played a pivotal role in supporting farmers in developing countries, substantially enhancing yields by 14 percentage points (Amarger, 2002). Although the researchers acknowledged the inclusion of some non-peer-reviewed studies and a few instances of unreported sample sizes, they made efforts to correct for publication bias by considering sources outside academic journals. This extensive dataset facilitated the control of potential confounding variables, such as fertilizer use. Significantly, the study also concluded that the source of funding did not influence the outcomes (Amarger, 2002). It's important to note that under specific conditions designed to isolate genetic yield factors, certain GM crops are known to exhibit lower yields, attributable to phenomena like yield drag or yield lag. However, these circumstances do not accurately reflect real-world field conditions, particularly when considering the impact of pest pressure, which is often the primary purpose of the GM trait. Moreover, the combined advantages of increased yield, reduced land use, decreased fertilizer application, and reduced reliance on farming machinery form a positive feedback loop, ultimately leading to a reduction in carbon emissions associated with agriculture (Sharma *et al.*, 2018). These emissions reductions have been estimated to account for approximately 7.5% of total agricultural emissions in the European Union, equivalent to 33 million tons of CO₂. Additionally, gene editing techniques, such as CRISPR-based gene knockout, show promise in increasing yields without relying on biocides or pesticides (Yetisen *et al.*, 2015). For instance, field test results in March 2022 demonstrated that CRISPR-based gene knockout of KRN2 in maize and OsKRN2 in rice resulted in grain yield increases of approximately 10% and 8%, respectively, with no discernible negative effects (Church *et al.*, 2012; Baldo *et al.*, 2013). GMOs have made substantial contributions to crop yield improvement. Some key findings in this regard include:

Resistance to pests and diseases

Tobacco, corn, rice, and several other crops have been genetically modified to incorporate genes that produce insecticidal proteins derived from *Bacillus thuringiensis* (Bt). The introduction of Bt crops between 1996 and 2005 is estimated to have led to a remarkable reduction of over 100 thousand tons in the total volume of insecticide active ingredients utilized in the United States, constituting a significant 19.4% decline in insecticide application (Finger *et al.*, 2011). However, in the late 1990s, a genetically modified potato designed to resist the Colorado potato beetle was withdrawn from the market due to resistance from major buyers who were concerned about potential consumer opposition (Sheridan, 2011). Papaya, potatoes, and squash have undergone genetic modifications to enhance their resistance to a range of viral pathogens, including the cucumber mosaic virus, which, despite its name, poses a threat to a wide array of plants. Virus-resistant papaya, developed in response to the papaya ringspot virus (PRV) outbreak in Hawaii during the

Table 1. GMOs currently use in agriculture.

Genetically conferred	Example organism	Genetic change
Herbicide tolerance	Soybean	Glyphosate herbicide (Roundup) tolerance conferred by expression of a glyphosate-tolerant form of the plant enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) isolated from the soil bacterium <i>Agrobacterium tumefaciens</i> , strain CP4
Insect resistance	Corn	Resistance to insect pests, especially the European corn borer, through expression of the insecticidal protein Cry1Ab from <i>Bacillus thuringiensis</i>
Altered fatty acid composition	Canola	High laurate levels were achieved by inserting the gene for ACP thioesterase from the California bay tree <i>Umbellularia californica</i>
Virus resistant	Plum	Resistance to plum pox virus conferred by insertion of a coat protein (CP) gene from the virus
Vitamin enrichment	Rice	These genes for the manufacture of beta-carotene, a precursor to vitamin A, in the endosperm of the rice, prevent its removal (from husks) during milling
Vaccines	Tobacco	Hepatitis B virus surface antigen (HBsAg) produced in transgenic tobacco induces an immune response when injected into mice
Oral vaccination	Maize	Fusion protein (F) from Newcastle disease virus (NDV) expressed in corn seeds induces an immune response when fed to chickens
Faster maturation	Coho salmon	A type 1 growth hormone gene injected into fertilized fish eggs results in 6.2% retention of the vector at one year of age, as well as a significantly increased growth rate

late 1990s, incorporated PRV DNA. By 2010, approximately 80% of Hawaiian papaya plants had been genetically modified to resist this devastating virus (Fleischer *et al.*, 2014). In 1998, potatoes were genetically engineered to withstand the detrimental effects of potato leaf roll virus and Potato virus Y. Unfortunately, due to poor sales, these modified potatoes were withdrawn from the market after a mere three years (Qiu, 2018). Yellow squash was similarly enhanced to resist not one but initially two, and then three different viruses, starting in the 1990s. These viruses include watermelon, cucumber, and zucchini/courgette yellow mosaic viruses. Squash became the second genetically modified crop to receive approval from US regulators, and this trait was later incorporated into zucchini (Frist, 2006). Recent years have witnessed the development of numerous corn varieties aimed at combatting the spread of Maize dwarf mosaic virus, a costly pathogen that results in stunted growth. This virus is carried by Johnson grass and transmitted by aphid insect vectors. While these modified corn strains are commercially available, it's important to note that resistance to this virus is not a standard feature among all genetically modified corn variants (Allen *et al.*, 2008). The pharmaceutical industry is another frontier for the use of GMOs (Table 1). In 1986, human growth hormone was the first protein pharmaceutical made in plants (Barta *et al.*, 1986), and in 1989, the first antibody was produced (Hiatt *et al.*, 1989). Both research groups used tobacco, which has since dominated the industry as the most intensively studied and utilized plant species for the expression of foreign genes (Ma *et al.*, 2003). As of 2003, several types of antibodies produced in plants had made it to clinical trials. The use of genetically modified animals has also been indispensable in medical research. Transgenic animals are routinely bred to carry human genes, or mutations in specific genes, thus allowing the study of the progression and genetic determinants of various diseases.

Tolerance to abiotic stress

Genetically modified organisms (GMOs) have been developed to enhance crop tolerance to various abiotic stresses, which are non-living environmental factors that can negatively impact plant growth and development. These abiotic stresses include drought, salinity, extreme temperatures, and nutrient deficiencies. GMOs designed for abiotic stress tolerance aim to improve crop yields and ensure food security, especially in regions prone to such stressors.

Improved nutrient content

Genetically modified organisms (GMOs) have been developed to enhance the nutrient content of crops, a process often referred to as "biofortification." Biofortified GMOs aim to address nutrient deficiencies in diets and improve the overall nutritional value of staple crops. Here are some examples of GMO crop improvements in nutrient content:

Golden-rice: One of the most well-known examples of biofortified GMOs is Golden Rice. It is genetically modified to produce higher levels of provitamin A (beta-carotene). This enhancement addresses vitamin A deficiency, which can lead to blindness and other health issues in regions where rice is a dietary staple (Paine *et al.*, 2005).

Biofortified cassava: Cassava is a major staple crop in many parts of Africa and South America. Biofortified cassava varieties have been developed to contain higher levels of essential nutrients, particularly vitamin A and iron, to combat deficiencies in these nutrients in local diets.

High-lysine corn: Corn is often deficient in the essential amino acid lysine. GMO corn varieties with increased lysine content have been developed to enhance the protein quality of corn-based diets (Naqvi *et al.*, 2009).

Zinc and iron-fortified crops: Biofortified crops, such as zinc-fortified wheat and iron-fortified beans, have been genetically engineered to contain higher levels of these minerals. This addresses deficiencies that are common in diets, particularly in developing countries.

Folate-enhanced crops: Folate (vitamin B9) is essential for human health, especially during pregnancy. GMO crops, like folate-enhanced rice, have been developed to increase folate levels in the diet, reducing the risk of neural tube defects in newborns (Goddijn et al., 1993).

High-protein soybeans: crops have been genetically modified to increase their protein content, providing a valuable source of protein in diets, especially for livestock feed.

Vitamin-enriched bananas: Biofortified bananas have been engineered to contain higher levels of essential vitamins, such as vitamin A and vitamin E, addressing dietary deficiencies in regions where bananas are a primary food source (Römer et al., 2000).

IMPACTS ON SAFETY

Genetically modified organisms (GMOs) have been extensively studied and regulated to ensure their safety. Numerous assessments have been conducted to address potential concerns related to human health and the environment. Key findings include:

Human health safety: GMO crops undergo rigorous allergenicity and toxicity assessments to identify and mitigate potential health risks. Comprehensive toxicological studies examine the impact of GMO consumption on human health, ensuring the safety of GMO-derived food products (EFSA, 2011).

Environmental safety: Ecological risk assessments assess the potential impact of GMO crops on non-target organisms, biodiversity, and ecosystems. Strategies are employed to minimize gene flow from GMO crops to wild relatives and non-GMO crops, reducing unintended genetic mixing (WHO, 2002).

Regulatory oversight: Regulatory agencies, such as the U.S. FDA and the EFSA, conduct safety evaluations before GMO crops can be commercialized, relying on data provided by developers. Continuous post-market surveillance monitors potential long-term effects and unanticipated health issues (NAS, 2016).

Consensus among scientific organizations: Leading scientific organizations, including the WHO and the National Academy of Sciences, assert that GMO crops currently on the market are safe for human consumption when properly tested and regulated (NAS, 2016).

Conclusion

In conclusion, the discussion surrounding genetically engineered

organisms (GEOs) in agriculture underscores the intricate balance between their potential benefits and the imperative need for safety and oversight. Undoubtedly, GEOs have demonstrated their capacity to enhance agricultural yield, bolster food security, and address the challenges posed by a growing global population. Yet, the ongoing vigilance regarding their safety remains paramount, necessitating comprehensive risk assessments and long-term monitoring to address ecological and health concerns. While the expanding body of scientific research offers promising avenues for sustainable agriculture through GEOs, it is equally crucial to prioritize rigorous regulation and transparent communication. By investing in better science communication, strengthening regulatory frameworks, and combating misinformation, we can ensure that the benefits of genetically modified (GM) crops are realized responsibly. Furthermore, advancements in precision gene-integration technologies and research in biofortification and stress tolerance hold promise for future progress in commercial agriculture. Ultimately, the path forward lies in harnessing the potential of GEOs while upholding the highest standards of safety, ethics, and regulatory oversight, thus paving the way for a more sustainable and productive agricultural future.

Authors contribution

Conceptualization, LNY and SB; methodology, SB; software, LNY; validation, AK, PP, PM and LNY; formal analysis, AK; investigation, SB; resources, PP; data curation, LNY; writing—original draft preparation, LNY; writing—review and editing, LNY; visualization, SB and PP; supervision, AK and PM; project administration, PM; All authors contributed equally to this work, all authors have read and agreed to the published version of the manuscript

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