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Environmental Effects Associated with Genetically Modified Crop Cultivation-A Review

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Abstract: This review critically examines the environmental effects associated with the cultivation of genetically modified (GM) crops, addressing the intense debates surrounding their potential impact. By synthesizing existing literature through a systematic approach encompassing peer-reviewed studies, meta-analyses, and scientific reports, the study aims to provide a nuanced understanding of the ecological consequences of GM *crop* farming. The primary objective is to inform policymakers, researchers, and stakeholders while advocating for standardized monitoring and research methodologies. The multifaceted environmental impacts are highlighted, revealing positive outcomes such as reduced insecticide use, improved soil conservation, and decreased greenhouse gas emissions. However, concerns arise regarding unintended effects on non-target organisms, gene flow to wild species, and the emergence of herbicide-resistant weeds. The review acknowledges disparities in study outcomes and methodologies, posing challenges in drawing definitive conclusions about the overall impact. The conclusion underscores the significance of continuous research to comprehensively evaluate the environmental implications of GM *crop cultivation*, emphasizing the need for rigorous monitoring, standardized methodologies, and long-term assessments. Recognizing the benefits, the study calls for context-specific evaluations to account for diverse agricultural settings and ecosystems. The establishment of standardized protocols for environmental impact assessments across various ecosystems is recommended, along with increased collaboration between multidisciplinary research teams, policymakers, and agricultural stakeholders to foster sustainable practices. Future research directions include a focus on long-term monitoring, robust risk assessments, and the development of innovative technologies to maximize the benefits of GM *crops* while mitigating potential adverse effects.

Keywords: Biodiversity; Genetically modified crops; Monitoring, Policy recommendations; Potential environmental impact; Risk assessment; Sustainability.

1. LITERATURE REVIEW

A comprehensive data collection process was implemented, involving an extensive search across a lot of reputable scientific databases. These databases encompassed PubMed, Science Direct, Google Scholar and web of science. The objective was to gather a diverse range of scholarly articles for studies related to the subject matter. The gathered data underwent examination to ascertain the possible ecological consequences associated with genetically modified crops. The assessment primarily focused on biodiversity, soil health, water quality, pesticide usage, and the emergence of herbicide resistance. The research's strengths and limitations were assessed, and conclusions were made based on the overall reliability and coherence of the studies.

2. INTRODUCTION

Progress in cellular and molecular biology has empowered the Handling of crop genetics through genetic engineering. This advanced technology enables the alteration of crops by transferring DNA from various sources to specific plants. This breakthrough presents possibilities to expedite and widen the enhancement of crops by incorporating genes that provide resistance against pests, diseases, herbicides, and environmental hurdles. Additionally, it entails boosting quality aspects like better post-harvest preservation, heightened taste, increased nutritional benefits, and enhanced coloration. Genetic modification and manipulation of plants have significantly enhanced crop yields through the introduction of advantageous genes from other sources or by suppressing the activity of natural genes within crop plants. Genetically modified crops Highlighted advantageous traits like herbicide tolerance, resilience against pests and diseases, increased ability to endure environmental pressures, and improvements in nutritional value. Transgenic crops hold undeniable potential to significantly enhance global food security and agricultural sustainability. A key benefit of this technology lies in its ability to access genes from diverse sources and introduce them into specific crops, enabling the development of enhanced varieties. Crops have been modified through genetic engineering to enhance their growth, productivity, and ability to resist pests and environmental challenges. Figure 2 illustrates the diverse sources of genetic variation and their potential applications in creating new varieties of crops. To date, nearly 525 different transgenic events in 32 crops have been approved for cultivation in different parts of the world. The adoption of transgenic technology has been shown to increase crop yields, reduce pesticide and insecticide use, reduce CO_2 emissions, and decrease the cost of crop production [1]. Probable ecological impact concerning these crops has gained significant attention, primarily due to worries about their impact on unintended organisms and the unintended spread of genetic material to wild populations. The main arguments of *GM* supporters are safe food security, improved food quality, and extended shelf-life. It will benefit not only both consumers and farmers, but also the environment [2]. Application of genome editing of plants in agriculture has sparked polarizing debates within academic publications. Within the context of the ongoing debate surrounding *GM crops*, an essential aspect to consider revolves around their environmental implications. Critics of genetically modified crops bring up legitimate worries, suggesting that the genes from these crops could spread to native populations, cultivating herbicide-resistant *GM crops* might result in higher herbicide usage, and the toxins produced by *GM crops* could find their way into the food chain, impacting unintended organisms. Additionally, there are growing apprehensions regarding the horizontal transfer of transgenic DNA, leading to its dissemination among unrelated species. On a global scale, the acceptance of genetic engineering has resulted in a decline in the utilization of pesticides, although the degree of this decrease fluctuates based on the crop type and the particular genetic trait that has been incorporated. It is estimated that the use of *GM* soya bean, oil seed rape, cotton and maize varieties modified for herbicide tolerance and insect protected *GM* varieties of cotton reduced pesticide use by a total of 22.3 million kg of formulated product in the year 2000 [3]. Arguments supporting *GM crops* include their potential superiority over traditional methods in managing specific pests, the possibility of enhancing agricultural biodiversity through herbicide-resistant *GM crops*, and the potential for reduced pesticide usage and lower greenhouse gas emissions associated with *GM crop* cultivation. These scientific arguments are concerned with the potential consequences of the use of *GM crops* [4]. Examination was done for getting the evidence for both beneficial and harmful impacts on Environment and biodiversity. Recent studies documenting negative impacts indicate that the risk assessment conducted internationally during the registration process for governmental approval of transgenic pest resistant crops may be overlooking some subtle and complex ecological effects on several trophic levels within and outside crop fields [5]. Agricultural biotechnology brings both benefits and potential drawbacks to the diverse and intricate systems of agricultural production. While genetically modified *(GM) crop* systems have the potential to mitigate certain environmental risks linked with traditional farming, they also bring about new challenges that require attention and resolution. In order to evaluate the environmental impacts of *GM crop* systems, their risks should always be weighed considering their potential benefits and current agricultural practice [6]. Extensive efforts have been made to investigate the possible hazards related with the utilization of genetically altered crops *(GMOs)*. These hazards encompass the Proliferation of herbicide-resistant plants and the prospect of genetic material spreading within native populations. These risks include the advancement of super weeds" or "weed-resistant plants and the potential for genetic material to spread among indigenous populations. Unintended Consequences of Biotechnology is shown in Table1. Globally, the scientific community is in intense discussions on the topic and extensive literature of the topic compelled us to illustrate the nature of impacts in detail. We focused to explain primary questions related to direct and indirect effects of *GMOs* on the environment [7]. A formalized framework of science-based risk assessment and risk management measures usually governs the intentional introduction into the environment or market of genetically modified organisms [8]. Genetically engineered crops involve the use of advanced biotechnology methods to modify the genetic makeup of plants. The alteration process may involve introducing genes from diverse sources such as plants, animals, or bacteria, which can impart different favorable characteristics like resistance to pests or tolerance to drought. Genetically modified crops provide benefits like higher yields and decreased dependence on pesticides, yet there are legitimate concerns regarding the potential ecological impact linked to their extensive adoption. Challenges arising from this situation include the transfer of genes to wild plant varieties, development of herbicide-resistant weeds and the potential harm to unintended organisms. This thorough evaluation critically assesses the environmental effects associated with growing genetically engineered crops. The broad integration and implementation of GM crops have ignited global discussions concerning their impact on the environment. Our study consolidates a wide array of empirical evidence and scholarly perspectives to elucidate the multifaceted dimensions of this issue. The review delves into examining the immediate effects and Secondary effects of cultivating genetically modified *(GM) crops* on diverse ecological elements. It evaluates changes in the variety of life, potential impacts on organisms not intended as targets, shifts in soil quality, and the overall transformations in ecosystems caused by the extensive use of genetically modified crops. Additionally, the paper explores the possible consequences of gene flow, increased weediness, and the emergence of pesticide resistance in agricultural ecosystems. This review aims to analyze and assess previous studies investigating the diverse environmental effects linked to the cultivation of genetically engineering crops. Its objective is to provide a Root for future research initiatives and policy discussions regarding agricultural practices. This review paper also aims to emphasize and delve into the environmental consequences of genetically modified *(GM)* plants. This extensively analyzed review serves as a valuable resource for policymakers, researchers, and stakeholders seeking to expand their understanding of the potential environmental impacts associated with genetically modified crops. It offers a thorough examination of the topic and presents valuable perspectives that can guide the creation of successful approaches to guarantee the secure and environmental- friendly utilization of these crops.

3. OBJECTIVES

I. A comprehensive investigation and in-depth evaluation of the present research discoveries concerning the ecological impacts of genetically modified crops. Through synthesizing and analyzing recent studies, the review aimed to accomplish the following goals:
II. Assess the state of knowledge,
III. Examine biodiversity implications,
IV. Evaluate pesticide use patterns,
V. Investigate soil health effects,
VI. Analyze gene flow and its implications,
VII. Examine ecological interactions and ecosystem services,
VIII. Identify knowledge gaps and future research needs.

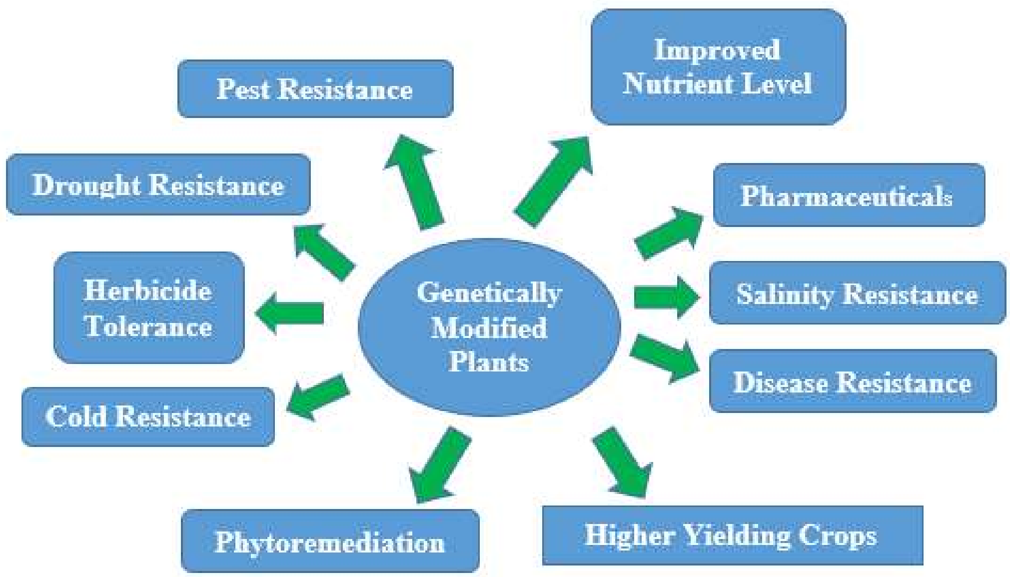

Fig. 1. Diversified Properties of Genetically Modified Plant

4. HISTORICAL BACKGROUND

In the annals of scientific history, 1946 stands as a momentous year, marked by the revelation that genetic material possessed the capacity to leap across species, an extraordinary finding that set the wheels in motion for the revolutionary field of modern genetic modification. This was followed by DNA double helical structure discovery and conception of the central dogma the transcription of DNA to RNA and subsequent translation into proteins by Watson and Crick in 1954. Consequently, a series of break through experiments by Boyer and Cohen in 1973, which involved “cutting and pasting” DNA between different species [9]. The advent of genetically modified organisms Note as a remarkable breakthrough in agricultural biotechnology, revolutionizing farming practices. Genetically engineered crops came into existence in the 1990s, propelled by significant scientific breakthroughs, signaling the dawn of their commercialization. These plants were engineered to exhibit particular characteristics via genetic modification, like improved ability to withstand herbicides or heightened immunity against insects. In 2008, genetically modified crops spanned an impressive 125 million hectares and were cultivated across 20 to 25 countries. The countries with the biggest share of the *GM crop* area were the United States (50%), Argentina (17%), Brazil (13%), India (6%), Canada (6%), and China 3% [10]. The primary goal behind the development of genetically engineered crops was to enhance agricultural productivity, increasing crop yields, and mitigate the challenges of global food security. These plants were genetically altered to gain advantageous characteristics by integrating genes from different organisms, providing them with capabilities such as defense against pests and diseases, as well as the ability to tolerate herbicides. Diversified properties of genetically modified Plant is shown in Figure 1. Despite the rapid adoption of *GM crops* by farmers in many countries, controversies about this technology continue. Uncertainty about *GM crop* impacts is one reason for widespread public suspicion [11]. The first *GM crop* was the *Flavr Savr tomato* which was developed by Calgene and approved for marketing by the US Food and Drug Administration (FDA) in1994 [12]. As genetically modified crops became more popular and widely used in agriculture, concerns arose about their possible adverse effects on the environment. People began to raise concerns about the potential unintended impacts on ecosystems and biodiversity resulting from the introduction of new characteristics into these crops. Table 2 illustrated the primary pros and cons of *GM crops*. A comprehensive study has been carried out to assess how genetically modified crops affect unintended organisms, including beneficial insects and wildlife. The primary goal was to determine whether these crops could disrupt the delicate balance of ecosystems and pose threats to species that were not initially targeted. Furthermore, the study examined the influence of genetically modified crops on pollinators like bees and butterflies, considering their vital role in pollination and the functioning of ecosystems. Pesticide use was another critical aspect of concern. The development of genetically engineered crops with built-in pest resistance traits aimed to reduce reliance on chemical pesticides. The complexity of ecological systems presents considerable challenges for experiments to assess the risks and benefits and inevitable uncertainties of genetically engineered plants. Collectively, existing studies emphasize that these can vary spatially, temporally, and according to the trait and cultivar modified [13]. Over time, studies investigating the ecological impact of genetically modified crops have consistently prioritized continual scientific inquiry, thorough risk assessment, and the advancement of sustainable farming practices. The widespread acceptance and progression of genetically modified crops have prompted extensive investigations aimed at evaluating their ecological consequences and advancements. Further investigation and a thorough examination of existing research are crucial to improve comprehension of the environmental consequences and guide the sustainable use of genetically modified plants in agriculture. A glimpse of *GM crop* in India is shown in Figure 2.

Table 1: Unforeseen Outcomes of Genetic Modification

Environmental	Agricultural	Health
Toxins found in pest-resistant *GMOs* represent a substantial danger to unintended organisms, potentially disrupting the equilibrium and well-being of ecosystems as a whole.	Unraveling the Complexity: Genetically Modified Plants Bolstering Pest Resistance Evolution	The proteins produced from transferred genes undergo transcription and translation processes, ultimately leading to allergic reactions in people.
The phenomenon of cross-species pollination bears the inherent risk of promulgating herbicide resistance genes across plant populations, thereby engendering the creation of formidable weed species that defy conventional control methods.	Famous biotech companies having mono plastic legal rights over *GM seeds*	During gene transfer, the adoption of antimicrobial resistance genes as markers may result in their transfer to pathogenic bacteria, leading to their widespread distribution.
Biodiversity may face detrimental consequences due to the eradication of pests, weeds, and even competing plant species.	Genetically engineered plants show two primary agricultural challenges in the forms of resistance to pesticides and herbicides.	Transferred gene could mutate and cause unexpected danger

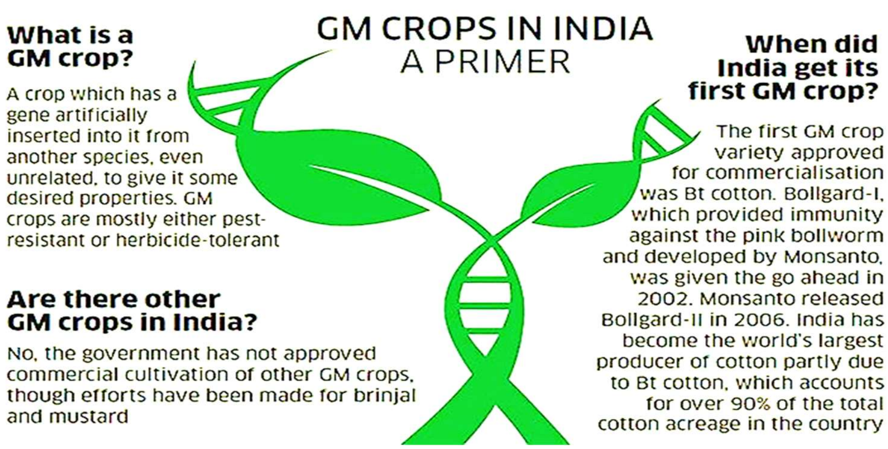

Fig. 2: *GM Crop* in India

Source-: https://www.drishtiias.com/daily-news-analysis/genetically-modified-gm-crops

Table 2: Main Advantages and Disadvantages of *GM Crop*

Advantages of *GM Crop*	Disadvantages of *GM Crop*
Increase in output, cost-effective items, Enhanced tolerance to drought. Reducing health risks Enhancing biodiversity promotion, integrating farmers' wisdom, and supporting water resource preservation. Higher vitamin content Ensure that food remains free from any traces of pesticides, herbicides, or fungicides. Increased mineral concentration and enhanced mineral diversity. Preserving insect populations.	Potential hazards associated with genetically engineered foods include possible toxicity, the creation of allergens, unintentional transmission of genes to non-genetically modified crops, the potential development of novel viruses and toxins, Limited seed availability caused by the patenting of genetically modified (GM) food crops, risk to agricultural biodiversity", Moral and societal issues, unclear labeling, opposition from animal rights supporters, and uncertainties about potential outcomes. Moreover, there is a possibility of *GM* plants spreading as invasive weeds, leading to broader concerns about their impact on non-target species and the environment, both directly and indirectly.

5. Risk on Biodiversity

Throughout the annals of plant breeding, the advancement of 'novel technologies' has been a recurrent practice aimed at engendering fresh gene amalgamations to enhance crop varieties. These methods included changing the chromosome count artificially, creating extra or modified editions of particular chromosomes, and employing chemical and irradiation technique to provoke mutations and reorganizations within chromosomes. Different methods using micro propagation or plant cell and tissue culture like protoplast fusion, in vitro fertilization, and Embryo culture, were used to help obtain hybrids between different species and within the same species. While this new technology shows potential for improving the reliance and quality of worldwide food production, concerns have been expressed by both the general public and scientific experts about the potential environmental effects and food security concern linked to genetically engineered crop plants. It is feared that the technology will harm people by undesired impacts on environment, health and/or the economic order at the expense of the poor. The public concern is becoming increasingly more vocal and sometimes violent [14]. Additionally, problems emerge due to the combination and resulting expression of the particular foreign gene in various organisms or species as a result of genetic inheritance. There are two main sets of possibility of harm linked with the introduction of transgenic crops. The first involves possible unintended consequences within the intended group, like potential negative effects on consumer health or the development of resistance in specific pests or pathogens due to the transgene providing resistance. The second set concerns unintended effects on non-target groups, which could lead to changes in local biodiversity connected to the transgenic plant or its genetic material extending beyond the plant's immediate environment. Although there are optimistic expectations for the future potential of genetically modified crops, numerous concerns exist regarding their environmental consequences. Biodiversity, encompassing the variety of species, genetic diversity, and ecosystems, plays a critical role in maintaining ecological balance and supporting agricultural productivity. Extensive scientific research has emphasized on understanding the ecological consequences of genetically engineered crop plants, particularly their impact on biodiversity. This topic has garnered significant attention, leading to thorough investigations aimed at comprehending the ecological implications. The widespread adoption of genetically modified crops, particularly those designed to tolerate herbicides, poses significant risks to the fragile equilibrium of ecosystems and the resulting decline in biodiversity. Weeds, despite their reputation for causing yield loss and contamination, actually possess certain eco-friendly qualities. One such aspect to consider is the significant reduction of soil erosion facilitated by weeds. To create approaches for evaluating extensive environmental dangers to biodiversity, socio-economic studies concentrate on how biodiversity interacts with society and the economy. These studies scrutinize the connections between biodiversity and four key factors influencing its changes: 1. Biological invasions 2. Climate shifts 3. Decline of pollinators and 4. Occurrence of environmental agents/ environmental toxins. The purpose of the socio-economic cross-cutting analysis is the construction of a decisional support useful for the management of biodiversity issues at European scale [15]. The monoculture practice used in the cultivation of GM crops has increased the risk of the emergence of herbicide tolerance and insecticide resistance between weed and insect pest species. This, in turn, may interrupt the food web at different trophic levels [16]. These resilient plants, with their extensive root systems, firmly anchor the soil, preventing its erosion by wind and water. Additionally, weeds contribute to the creation of a diverse and nurturing habitat for a wide array of beneficial organisms. By providing shelter, food, and nesting opportunities, these opportunistic plants support the existence and survival of numerous species, ultimately fostering a balanced ecosystem. In this sense, weeds can be seen as environmental allies, promoting soil stability and biodiversity conservation. Research findings have suggested that compared to conventional systems, genetically modified systems demonstrate a significant decrease in the variety, abundance, and overall amount of seeds stored in farmland seed banks. In the UK Farm Scale Evaluations, a noteworthy decrease of 20–36% was observed in the weed seed bank interestingly, dicot weeds were found to be more susceptible to this reduction compared to monocots, as stated in the report. The swift and extensive destruction of habitats will trigger cascading effects on the complex interconnectedness of species and their reliance on one another for sustenance, resulting in substantial impacts on food webs and the availability of food. The equilibrium inherent in predator-prey dynamics takes on heightened significance, not just for the welfare of beneficial organisms, but also in broader contexts. It is evident that this sequence of events will have cascading effects, disturbing the intricate balance of interactions among three trophic levels and symbiotic associations, thus resulting in intricate disturbances within the complex network of the food web. It is obvious that such disturbance in weed, insect and pest management will, in turn, end up with increased use of pesticides [17]. The change in resource availability sets off a chain reaction, affecting organisms at higher trophic levels in various ways. The application of glyphosate, a commonly used herbicide, can have a profound impact on foraging behavior. A striking example of this phenomenon was observed as spiders, in response to repeated exposure to glyphosate, exhibited a pronounced inclination towards excessive killing of crickets, deviating from their typical foraging patterns. Disruptions to the food web can trigger a succession in trophic relationships, leading to detritivores assuming the ecological niche formerly occupied by herbivores. Studies conducted on agricultural fields where glyphosate-tolerant maize and soybean are grown have revealed fascinating changes in the soil's biota dynamics. Glyphosate application has resulted in a noticeable increase in fungal biomass compared to bacterial biomass. These findings have prompted a hypothesis that revolves around the idea that modified carbon and nitrogen ratios, stemming from the use of glyphosate, could be initiating a transformation in the soil food web, characterized by sluggish nutrient cycling and intensified enrichments. The wide-scale adoption of *GM crops* such as *Bacillus thuringiensis (Bt) cotton* has resulted in some ecological issues [18]. The factors involved in disturbance of Farm land biodiversity include types of herbicides and insecticides used, degree of adoption, frequency of application, timing of herbicide or insecticide application, target crop, rotational and agronomic practices adopted, local fauna and flora, alternate hosts for friendly insects, microclimatic conditions, management history and surrounding habitats [19]. Recent studies have revealed that the use of *Baccaneer*® plus, which is a product containing glyphosate, has been found to decrease the migratory tendencies of the agrobiont wolf spider, scientifically named *Pardosa milvina*. This finding suggests a disruption in the intricate balance of predator-prey interactions within the food chains throughout the eastern United States. Similar to the controversies surrounding herbicide resistant *GM crops, Bacillus thuringiensis crops* have also raised questions regarding the potential risks they pose to biodiversity. Pesticides used in conjunction with *Bacillus thuringiensis crops* can extend beyond the boundaries of crop fields and have notable effects on nearby terrestrial and aquatic ecosystems. Additionally, the presence of these crops may impact local plant populations in close proximity to the land. The central focus of scientific inquiry regarding *Bt toxicity* lies on mammals and birds, with a multitude of studies revealing limited or insignificant signs of harm in these particular animal categories. A more comprehensive evaluation reveals that the cultivation of genetically modified crops engineered for herbicide resistance adversely affects biodiversity. The study focused on genetically modified corn designed to resist pests like beetles and butterflies, while also being resistant to glyphosate. The primary emphasis of the study was on studying the *arthropod food webs,* and it utilized a population of 243,896 individuals for experimentation.

5.1 Influence on Non-Intended Organisms

The concept of *"non-target"* organisms *(NTO)* has become common in debating the biosafety of *GMPs*, the specific risk assessment of which is often required by law. For instance, the European Directive *2001/18/EC* provides the legal background for *NTO testing*, requiring the assessment of possible changes in the interactions of *GM plants* with *NTOs prior* to their commercial release [20]. Numerous studies have provided evidence suggesting that certain genetically engineered crops, specifically those incorporating insecticidal proteins such as *Bacillus thuringiensis crops*, can potentially impact non-target organisms directly. *GM plants* can have indirect effects on both target and non-target organisms at different trophic levels through food webs [21]. Influence of *Bt (Bacillus thuringiensis) crops* extends beyond the specific insects they are designed to target, potentially impacting a range of organisms within the agricultural ecosystem surrounding the crops. Studying the influence of genetically modified crops on organisms that have intricate associations with plant roots has emerged as a significant field of investigation among scientists. Currently, insect-resistance in crops is based on expression of *crystalline (Cry) proteins* and *vegetative insecticidal proteins (e.g., Vip3A)* following insertion of *Bacillus thuringiensis* genes. There are numerous variations of *Bacillus thuringiensis proteins*, each of which act against a narrow set of insect pests *e.g., Lepidoptera, Coleoptera, or Diptera larvae* in a range of crops [22]. Researchers have particularly focused on understanding the consequences for mycorrhizal symbionts, which are mutually beneficial partners that contribute to nutrient absorption and overall plant well-being. Arbuscular mycorrhizal fungi, a group of advantageous microbes, are known for their ability to form mutualistic symbiotic relationships with the roots of the majority of plant species. Their role as bio fertilizers is indispensable, underlining their paramount significance in enhancing plant growth and nutrient absorption. Direct effects are usually easier to detect than indirect effects. For example, transgenic proteins, which have a range of activities against insects or pathogenic fungi and bacteria, may affect also non-target microorganisms, such as beneficial symbionts and/or microbial soil communities involved in organic matter decomposition [23]. Table 3 Demonstrates the genetic modification of different crops such as *Gossypium herbaceum*, *Zea mays*, *Solanum tuberosum, Lycopersicon esculentum, Oryza sativa*, *Solanum melongena*, and *Brassica oleracea* by introducing genes obtained from a soil bacterium known as *Bacillus thuringiensis*. The genetic code contained within these genes results in the production of proteins that exhibit outstanding efficiency in dealing with numerous important pests. The genetic manipulation of cotton plants involves the incorporation of insect toxin genes, *Cry1Ac and Cry1Ab/c,* which possess high effectiveness against *Lepidoptera* pests like cotton *bollworm (Helicoverpa zea, Helicoverpa armigera), pink bollworm (Pectinophora gossypiella),* and tobacco *budworm (Heliothis virescens)* [24]. GM crop risk assessment protocols should be based on biomass, cocoon production, percentage of cocoon hatching, as well as survival, biomass, growth and development of offspring as measurable endpoints, which characterize the population turnover rate [25]. The genetic makeup of maize has been altered to incorporate insect toxin genes that primarily target pests belonging to the order *Lepidoptera.* Scientists have developed genetically modified genes to effectively address the harmful impact of the European corn borer *Ostrinia nubilalis* on zea maize cultivation [26]. The potato has been genetically modified to possess insect toxin genes, specifically the *Cry3A genes*. This modification targets pests belonging to the order *Coleoptera*, which includes *beetles*. The primary focal point of our efforts lies in combating the *Colorado potato beetle (Leptinotarsa decemlineata)*, a notorious intruder known to inflict significant harm upon potato crops, thereby necessitating our unwavering dedication to safeguarding their well-being. With the aim of addressing *Lepidoptera* infestation, tomato plants have been genetically enhanced through the integration of *Cry1Ac (Crystaline entomocidal protoxin. Insecticidal delta-endotoxin CryIA(c))* insect toxin genes. This innovative genetic modification targets and controls key pests such as *Helicoverpa zea, Helicoverpa armigera, Pectinophora gossypiella, and Heliothis virescens,* ensuring improved pest management strategies. *Cry1Ab*, an insect toxin gene found in rice, specifically targets pests belonging to the order *Lepidoptera,* which includes *moth* and *butterfly larvae*. The major pests that *Cry1Ab* aims to control are *Scirpophaga incertulas* and *Chilo suppressalis*.

5.2 Effects on Pollinators

Most of the existing research on the safety of *GM crops* for pollinators has been focused on honeybees or bumblebees as focal species; existing evidence from scientific literature and two decades of cultivation of *GM crops* support the belief that there are no negative effects of currently cultivated insect-resistant *GM crops* for insect pollination services [27]. The effects of agriculture, particularly those employing genetically modified and intensive modern farming methods, raise ecological concerns. However, there's limited understanding regarding their impact on wild bee populations and how this might affect pollination and its consequences. The participation of pollinators, such as bees, butterflies, and other insects, assumes utmost importance as they contribute significantly to the pollination of flowering plants, including several crop species, thereby influencing food production and ecosystem stability. Numerous research work have focused to investigate the potential immediate consequence of genetically engineered crops on pollinator populations. Many academic research papers have thoroughly investigated the impact of *Bacillus thuringiensis plant* pollen on honey bees, with considerable focus on understanding different aspects of their biology and behavior. These investigations involved feeding tests, where honey bees were exposed to *Bt plant* pollen, and the results consistently revealed no significant effects on multiple parameters. The focal point of scientific inquiries has predominantly been on genetically modified crops that possess the capacity to synthesize insecticidal proteins, notably the well-studied *Bacillus thuringiensis (Bt)* toxins. These proteins have been strategically expressed in specific plant tissues that do not directly engage in pollination, resulting in negligible or minimal ingestion of Bt toxins by pollinators. Most genetically engineered crops are considered to have a low likelihood of causing acute toxicity to pollinators as a result.

5.3. Pesticide Use

Pest predators and parasitoids

Since the advent of *genetically modified (GM) crops* in the late 1970s, we have witnessed an unprecedented increase in the development and commercial use of this technology worldwide. The dominant *GM traits* nowadays include insect resistance, expressing *Bacillus thuringiensis (Bt)* and digestive enzyme inhibitors, and herbicide tolerance, tolerating applications of particular herbicides [28]. Many important research studies have explored how genetically modified crops designed to resist insects affect beneficial unintended insects such as ladybirds, lacewings, and parasitic wasps in the environment. A recent study showed the asynchronous development of *Bt-resistant* and *Bt-susceptible* pink bollworm larvae reared in greenhouse bioassays [29]. Transgenic Bt cotton that contains Cry1Ac/Cry2Ab or Cry1Ac/EPSPS genes doesn't have an impact on the plant bug Adelphocoris suturalis or the pollinating beetle Haptoncus luteolus as shown in Figure 4.Considerable investigation has been conducted to assess the impacts of Bacillus thuringiensis cotton and Bacillus thuringiensis maize on predators and parasitoids within intricate ecological frameworks known as tri-trophic systems. These systems encompass the interconnected relationships between plants, herbivores, and the natural enemies that prey upon them. When predators were exposed to prey susceptible to the *Bt toxin*, research indicates that they experienced adverse consequences such as lower survival rates among larvae, decreased consumption rate, and reduced body mass. Conversely, no discernible effects were identified when prey that were *either Bt-insusceptible* or herbivores subjected to sub-lethal damage were utilized. There were no adverse consequences observed when predators consumed *Bt plant tissues*, such as maize pollen. Studying the impact of Bacillus thuringiensis (Bt) crops on beneficial organism populations that feed on insect pests was illustrated in Table 4.

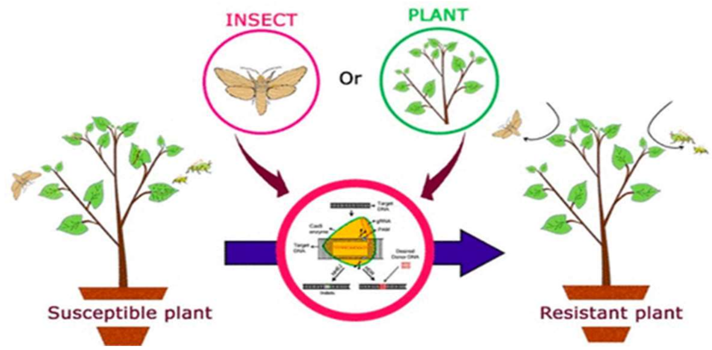

Fig. 3: Genome editing in plants for resistance against insect pests for crop improvement
Source-: https://pubs.acs.org/doi/10.1021/acsomega.0c01435

Table 3 Investigating the effects of *Bacillus thuringiensis* transgenic crop on the beneficial microbiota that prey on insect pests.

Plants	Toxin	Predator/	Vector	Vulnerable in the host to the toxin	Observed outcome
Gossypium herbaceum	Cry1Ac	Propylaea japonica., Chrysoperla carnea	Lepidoptera Lepidoptera	Yes Yes	Negative Negative
Zea mays	Insecticidal protein Cry1Ab	Neoseiulus cucumeris.	Acary	No	No
		Stethorus punctillum,	Acary	No	No
		Chrysoperla carnea	Homoptera	No	No
Solanum tuberosum	ry1Ac9, Cry9Aa2	Micromus tasmaniae	Hemiptera	No	No
Oryza sativa	Insecticidal protein Cry1Ab	Pirata (Lycosidae, Araneae)	Lepidoptera	Yes	Yes, Negative

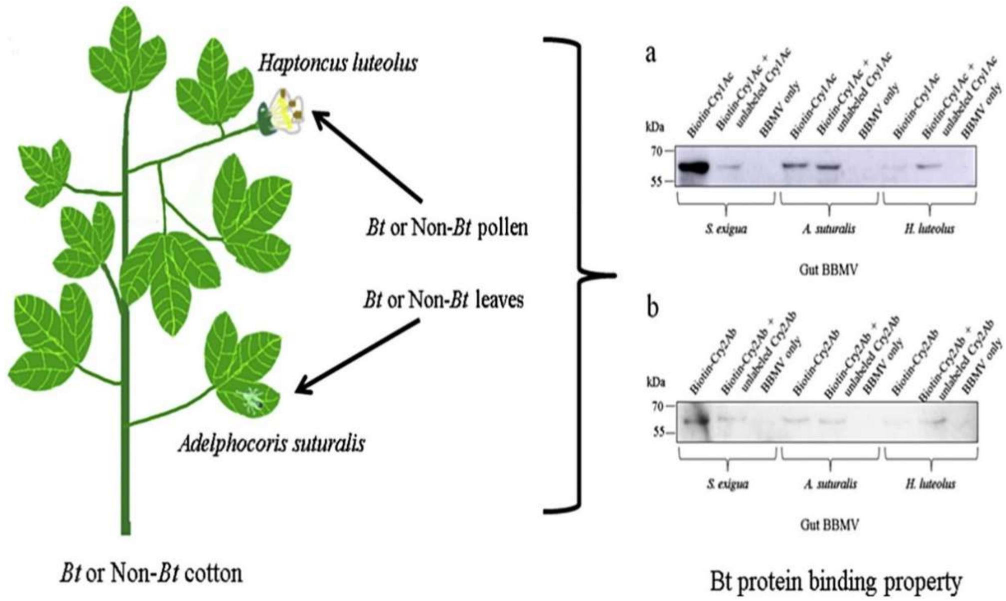

Fig. 4: Transgenic Bt cotton expressing *Cry1Ac/Cry2Ab or Cry1Ac/EPSPS* does not affect the plant bug *Adelphocoris suturalis* or the pollinating beetle Haptoncus luteolus

Source-:https://ars.els-cdn.com/content/image/1-s2.0-S0269749117329275-fx1_lrg.jpg

Table 4: Bacillus thuringiensis gene-modified crop varieties developed to protect against specific pests

Transgenic crop plants	Genes producing insecticidal proteins	Pest targeting sequence	Hierarchy of targeted insects
Gossypium herbaceum	insecticidal crystal protein, Cry IA(c)	Glossata (Moths, Butterflies, Skippers)	*Pectinophora gossypiella, Helicoverpa zea, Helicoverpa armigera,* and *Heliothis virescens*.
	crystal protein (Cry1Ab/c)	Glossata (Moths, Butterflies, Skippers)	,Pectinophora gossypiella,Helicoverpa armigera,Helicoverpa zea, Heliothis virescens
Zea mays	Cry1Ab	Glossata (Moths, Butterflies, Skippers)	European corn borer (Ostrinia nubilalis)
Solanum tuberosum	Cry3A	Coleoptera	Colorado potato beetle (Leptinotarsa decemlineata)
Lycopersicon esculentum	Cry1Ac	Glossata (Moths, Butterflies, Skippers)	Heliothis virescens, Helicoverpa armigera,Helicoverpa zea, Pectinophora gossypiella.
Oryza sativa	Cry1Ab	Glossata (Moths, Butterflies, Skippers)	Scirpophaga incertulas,Chilo suppressalis
Solanum melongena	δ-endotoxin or Cry1Ac	Glossata (Moths, Butterflies, Skippers)	Leucinodes orbonalis (Shoot and Fruit borer)

6. IMPACT ON SOIL AND WATER

The swift expansion of global agricultural land using genetically modified crops might lead to potential environmental impacts, including alterations in soil microbial activities. Soil biota perform crucial roles such as decomposing organic matter, cycling nutrients, facilitating oxidation-reduction reactions, enabling biological nitrogen fixation, and enhancing nutrient solubilization. Possible consequences of introducing *GM crops* on groundwater and water reservoirs are still being debated among scientists and farming communities. Glyphosate-resistant crops (GRCs), genetically engineered to endure glyphosate-based herbicides, have been extensively grown in the euro atlantics and, to a limited extent, in other geographical areas. In countries where they've received approval for cultivation, these crops have typically risen to prominence and become the dominant choice among farmers. The impact of N-(phosphonomethyl) glycine on soil and water is comparatively low compared to the effects caused by the herbicides it replaces when adopting genetically modified crops resistant to herbicides *(GRCs)*. A notable indirect result is that genetically modified crops (GMCs) promote the transition to reduced- or no-plow agricultural techniques, resulting in a significant reduction in both soil erosion and water contamination. Glyphosate and its degradation product, *aminomethylphosphonate (AMPA),* residues are not usually detected in high levels in ground or surface water in areas where glyphosate is used extensively [30].This discussion pertains to the degree and quantity of herbicide utilization in genetically modified crops. It is widely recognized that *GM crops* possess herbicide tolerance, which encourages the widespread application of broad-spectrum herbicides. The rise in herbicide usage occurred indirectly, wherein a less environmentally persistent and more toxic herbicide was substituted with glyphosate. To put it differently, there has been a general decline in the usage of harmful herbicides, while the use of herbicides containing glyphosate has seen a rise. *Glyphosate*, possibly the most extensively utilized herbicide globally, can penetrate the soil via different pathways like direct exposure during initial or post-harvest spraying, runoff, or seepage from vegetation. Additionally, it can be released through root secretions or the decomposition of plant material. The presence of glyphosate in water on farmland and its subsequent effects on aquatic ecosystems and aquatic organisms are clearly visible. The limited possible damage caused by glyphosate to non-target soil organisms is commonly linked to its shorter duration in comparison to many other weed killers and its robust soil-binding characteristics, which limit its extensive impact. The impact of glyphosate on antimicrobial activity is a topic of discussion due to the potential disruption it may cause to microbial communities on a large scale when applied extensively in farming. *GM crops* can transfer *Bt toxins* to soil and water through multiple channels, including the discharge of pollen during the flowering process, the secretion of substances by plant roots, and the existence of residues from genetically modified plants. There is available evidence suggesting that *Bt toxins* have the ability to attach to clay and humid substances, which makes the proteins capable of being broken down by natural processes. Genetically modified crops are known for their resistance to herbicides, prominent to increased reliance on herbicides that target various plants. This change indirectly led to substituting a more environmentally enduring and harmful weed killer with glyphosate. While overall harmful herbicide usage has decreased, there has been a noticeable increase in the use of glyphosate-containing herbicides. *N-(phosphonomethyl)* glycine[3], considered one of the most widely used herbicides worldwide, can infiltrate the soil via different routes like direct exposure to treated regions during initial or post-crop season applications, flow-off from plants, seepage, root discharge, or decomposition of plant material. The evident presence of glyphosate in agricultural water systems and its consequential effects on aquatic ecosystems and the organisms within them are clear. However, most experts consider the potential damage caused by glyphosate to Non-intended organisms in the soil to be minimal because it persists for a shorter duration compared to many other herbicides and strongly attaches to the soil composition. The impact of glyphosate on antimicrobial activity is a subject of contention due to the potential disruption it may cause to microbial communities on a large scale when extensively applied in agriculture. Similarly, *Bt toxins* from genetically modified crops can be transferred to soil and water through various means, such as pollen deposition when the plants are flowering, the release of substances from the roots, and the residues of *GM plants*. *Bt toxins* have been observed to attach to clay and damp substances, making the proteins more susceptible to breaking down naturally. Statistical analysis revealed no considerable variance in pH levels between Cry1Fa2 *GM maize* and wild plant of *zea maize*. Various research works have indicated that *Bt proteins* sourced from genetically modified plants degrade swiftly once they enter the soil, with only a minimal amount persisting for an extended period. The longevity of *Bt toxins* in the soil predominantly is based on the specific toxin variant and soil characteristics, rather than the quantity of actively produced transgenes. Altered crops might impact water resources by reducing the need for irrigation, thereby aiding in water conservation. Herbicides could potentially contribute to water contamination. The effect of genetically engineered crops on soil health can be multifaceted. Some studies suggest positive effects on soil health due to genetically modified crops, such as increased microbial activity and organic matter. However, other research has found adverse effects, including reduced soil biodiversity and heightened weed resistance. Research indicates that certain GM crops, like *Bt crops*, can induce alterations in soil microbial communities.

7. THE IMPACT ON THE TRANSFER OF GENES

Transfer of genes or gene flow is regarded as a significant driving factor in evolution that introduces alterations in the frequencies of genes, akin to mutation, genetic drift, and selection. Gene flow can impact the environment by diminishing the distinctions between populations and promoting greater diversity among individuals within a population. Gene flow is responsible for shaping the configuration of genetic diversity. In the upcoming years, several kinds of genetically modified rice (Oryza sativa) will become available for commercial use. These varieties will possess enhanced characteristics such as increased yields, improved ability to withstand both living and non-living challenges, resilience against herbicides, better nutritional value, and the introduction of new medicinal proteins. Despite rice being mainly self-pollinating, the genes introduced in these modified varieties are anticipated to spread to neighboring wild and weedy rice plants through the transfer of pollen, a process known as pollen-mediated gene flow. Pollen mediated gene flow *(PMGF)* is the major pathway for transgene escape [31]. Introducing genetically modified organisms (GMOs) not native to an ecosystem carries potential long-term environmental risks, making it challenging to accurately predict outcomes. Professionals across various fields globally are concerned about the potential transmission of genetic material from genetically modified organisms (GMOs) to closely related wild species or weeds. This transfer could occur through mechanisms such as horizontal gene transfer or hybridization, raising significant apprehensions among experts. Certainly, gene flow can lead to diverse environmental consequences, and although the precise impacts may differ case by case, there are overarching conclusions that can be broadly applied to many scenarios. Gene flow in common crops has been divided into three classifications according to the degree of potential risk they present: high, medium, and low in Figure 6. This classification aids in the identification and management of potential risks linked to the spread of genes in these crops. These concerns encompass a range of issues, including the possible rise of highly resilient weeds, the emergence of new viral diseases, the unpredictable behavior of genetically modified organisms in natural surroundings, the creation of gene manipulation methods with far-reaching effects, and the development of pests and diseases that can resist newly developed treatments. Additionally, it's vital to consider the ancillary consequences of gene flow, such as effects on non-target organisms, disruption of biodiversity, displacement and possible extinction of species, disturbance to soil microenvironments, and effects on ecologically significant species. The likelihood of new species emerging should not be overlooked, potentially leading to a wide range of interactions among living beings. It is reasonable to acknowledge the possibility of gene flow from genetically modified crops, as similar instances have occurred naturally over thousands of years between sexually compatible species. The anticipation relies on fundamental factors like the proximity of compatible plant species, coordination of blooming periods, ecological interactions with the recipient species, and, of course, sexual compatibility. Genes possessing particular features are better suited for integration into natural populations. These traits include dominance, absence of connection with detrimental crop alleles, and their existence on common genomes or similar chromosomes. Studies have been conducted to create mathematical models that predict the potential transfer of genes through pollen movement. Research has been conducted in multiple crops like, *Brassica napus zea maize*, *Gossypium herbaceum*, *Triticum aestivum*, *Hordeum vulgare*, *Phaseolus vulgaris*, and *Oryza sativa*. The transmission of genes via pollen depends solely on aspects associated with the plant's pollination biology. These aspects encompass the quantity of pollen produced, the breeding system between the species donating and receiving genes, the level of crossbreeding, the comparative concentrations of both species, the different agents aiding the process (such as wind, air movement, water flow), and environmental conditions like temperature, moisture, and brightness. The direction of the wind had a notable impact on the transfer of genes through pollen. As the distance grew between the pollen source and N12-1, a type of genetically modified wheat resistant to WYMV, there was a significant decrease in gene transfer through pollen. The transfer of pollen in transgenic corn, canola, and creeping bent grass significantly declined after only a 30-meter, 20-meter, and 20-meter increase in distance, respectively. Notably, creeping bent grass and rigid ryegrass demonstrated the highest frequency of gene flow due to pollen movement, even when the pollen donor was located 2000 and 3000 meters away. Self-pollinated crops exhibit a lower occurrence of gene flow compared to cross-pollinated crops. Gene flow is by definition the active or passive dispersal of genes via seed, pollen or clonal parts of a plant into the environment [32]. For instance, when examining the transfer of genes from rice to red rice weed and vice versa through pollen, the observed frequency was less than 1%. At the landscape and regional scale, additional factors influence gene flow, including the ratio of donor and recipient fields, the shape and topography of fields, and environmental factors [33]. Two other ways that aid in gene flow are seed-mediated transfer and vegetative propagule-mediated transfer. Seed-mediated gene transfer might happen through human errors during actions like planting, harvesting, or handling crops after harvesting. It can also occur due to the existence of unintended plants. Instances of unintentional genes that confer herbicide resistance have been observed in harvested seeds of various crops like corn, wheat, and canola. This transfer of genes from one plant to another can occur through the vegetative parts of plants or through different animals. Various origins of genetic diversity and their potential uses in developing new types of plants shown in Fig. 5. The introduction of new traits and genes through genetic engineering raises further concerns, as it allows for the transfer of genes into different crops that have varying abilities to cross-pollinate. Genetically modified crop plants have the potential to crossbreed with sexually compatible species, leading to potential environmental consequences due to the development of hybrid plants and their progeny. The possible effects of genetically modified crop plants on the surrounding environment is show in Table 5

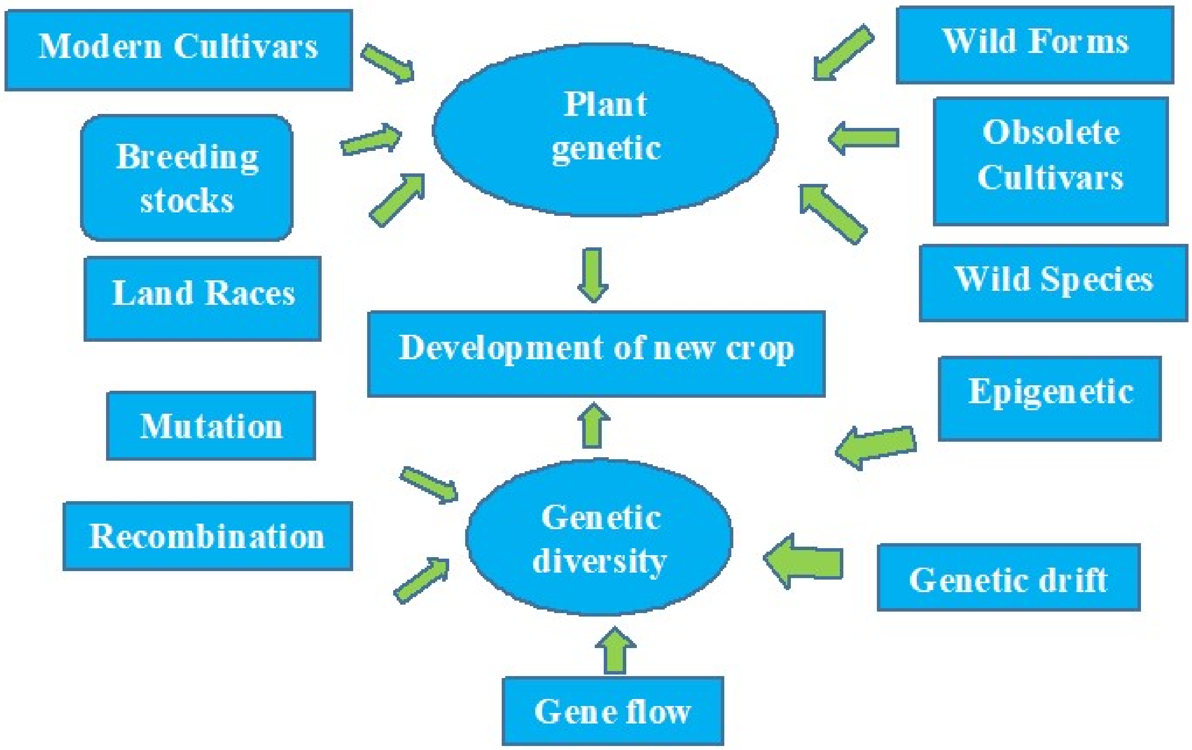

Fig. 5: Different sources of genetic variation and their potential applications in creating novel plant varieties.

Table 5: Realizable impacts of transgenic crop plants on the environs

Class	Example
The principal effects of emerging characteristics on the environment	

Chemical interactions with organisms or living entities.	Unintended impacts of insect resistance: Destiny and aftermath of insect-killing poisons in the soil.
Alteration in the enduring nature or invasive characteristics of the plant species.	Continued presence in farming settings (weed-like traits) and the inclination to invade and dominate in native ecosystems.
The transfer of genetic material through pollination to undesirable plants such as weeds and feral plants.	Expressing herbicide tolerance in weeds, transferring both biotic and abiotic stress resistance to wild or feral species, and combining multiple genes for herbicide tolerance.
Secondary effects of new traits on the environment	
Decreased effectiveness in managing pests, diseases, and weeds.	The rise of weeds tolerant to herbicides due to natural evolution and selective forces among the weed community. Likewise, the development of immunity to Bt toxins in pests through evolutionary changes.
Impact on the diversity of animal species.	Herbicides with a broad spectrum of targets cause varied impacts on both the environment and living organisms.
Impact on water and soil.	Changes in the use of weed-killing substances Adaptations in the techniques for preparing soil

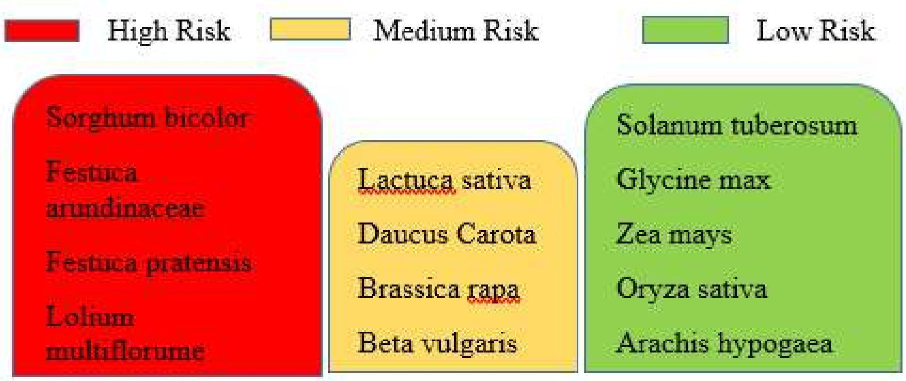

Fig. 6: Gene transfer among commonly cultivated crops has been divided into three classifications according to the degree of danger they pose: high, moderate, and minimal. This categorization aids in recognizing and controlling the possible hazards linked to gene transmission within these cultivated plants.

8. Future perspectives

Genetically modified crops have brought about a significant transformation in contemporary farming practices, presenting prospects for tackling worldwide issues like ensuring sufficient food supply, mitigating climate change, and promoting sustainable agriculture. Scientific institutions globally have extensively researched the safety of genetically engineered organisms (GMOs), and their collective agreement is that the GMOs presently accessible for consumption are deemed safe based on their investigations. Reputable scientific institutions like the National Academy of Sciences (NAS) in the U.S., the European Food Safety Authority (EFSA) within the European Union, and the World Health Organization (WHO) have confirmed the safety of genetically modified organisms (GMOs). These organizations have conducted thorough scientific assessments and have concluded that GMOs are safe for consumption. Several scientific studies have consistently validated the positive effects of *GMOs* on enhancing crop productivity and the sustainable future of agriculture. New research indicates that genetically modified crops, such as *Bt crops* that repel insects and herbicide-tolerant crops, can potentially increase crop productivity, reduce harm from pests, and decrease reliance on pesticides. In a comprehensive investigation that incorporated diverse assessments of Bt cotton cultivation, significant decreases in insecticide usage were observed, accompanied by enhanced crop yield and improved financial benefits for farmers. On a global basis GM technology has reduced pesticide use, with the size of the reduction varying between crops and the introduced trait. It is estimated that the use of GM soybean, oil seed rape, cotton and maize varieties modified for herbicide tolerance and insect protected GM varieties of cotton reduced pesticide use by a total of 22.3 million kg of formulated product in the year 2000 [34]. Studying the ecological impacts of genetically engineered organisms *(GMOs)* has been pivotal in encouraging informed decision-making grounded in trustworthy evidence. Recent scientific evidence indicates that the environmental effects of genetically modified organisms have been thoroughly investigated, considering factors such as biodiversity, gene flow, and ecological interactions. These studies suggest that the overall environmental impact of GMOs is typically similar to or possibly even lower than that of traditional crops. A thorough examination of various studies concluded that Bt crops had limited negative impacts on non-target organisms and did not present significant threats to the functioning of ecosystems. Farm surveys of randomly selected households cultivating insect-resistant GM rice varieties demonstrate that when compared with households cultivating non-GM rice, small and poor farm households benefit from adopting GM rice by both higher crop yields and reduced use of pesticides, which also contribute to improved health. For rice, the development and implementation of appropriate resistance management strategies, and resolution of trade policy barriers, are key constraints that have delayed earlier widespread cultivation of the crop [35]. Recent studies suggest that genetically engineered crops have brought about economic benefits for farmers, such as higher profits, decreased production expenses, and enhanced livelihoods, particularly in developing nations. Consumer opinions and attitudes towards genetically modified organisms have played a significant role in shaping regulatory choices and labeling policies. Researchers have conducted scientific investigations to delve into consumer preferences, perceptions, and understanding of GMOs.

9. DISCUSSION AND CONCLUSION

A genetically engineered crop plants having a lot of varieties whose genetic material has been modified or changed through genetic engineering procedure such as gene splicing or gene editing, to introduce specific desirable traits. These modifications can enhance qualities like resistance to pests, tolerance to herbicides, improved nutritional content, or better adaptability to environmental conditions. This method of genetic manipulation involves implant genes from either the same species or different species, allowing the creation of new types of crops that can exceed the usual constraints of traditional species. The benefits of transgenic crops in addressing food insecurity and malnutrition in society have been firmly established. The progress in creating genetically engineered crops thus far appears to have been conscientious, and regulatory bodies have generally exercised prudence when approving the release of genetically engineered varieties. Genetically engineered crops globally improve yield, reduce pesticide dependency and sustain resilience to environmental stresses. Despite their widespread adoption and benefits, a comprehensive evaluation and efficient management strategies are vital to mitigate potential adverse environmental effects. A thorough, ongoing research and analysis are crucial for a comprehensive study of the environmental consequences linked with genetically modified crops. Recent recognition of the researchers for the development of a genome editing technique using CRISPR/Cas9 by the Nobel Prize committee is another step closer to developing and cultivating new varieties of agricultural crops [36]. Although GM crops have the potential to boost agricultural productivity, substantial concerns about biosafety persist regarding their cultivation. Researchers and policymakers are increasingly exploring unintended consequences such as gene flow, unprotected genetic material transmission, increased weed-like behavior, and potential chemical toxicity. Recent studies suggest that *GM crops* have negative environmental effects, altering crop spread, developing resistance to pesticides, stacking transgenes, changes in crop presence, tolerance to chemicals, and disrupting biodiversity. Most studies align in their findings, but data remain insufficient. This review comprehensively examines the environmental implications linked to the cultivation of *GM crops* through literature search across various reputable scientific databases. A thorough investigation has been carried out into the broad effects of gathering data, covering immediate and secondary impacts on ecosystems, biodiversity, soil quality, unintended consequences on organisms, shifts in pesticide usage, genetic transmission, and the increase of Pesticide/herbicide resistance. Table 4 displays genetically modified crop varieties containing Bacillus thuringiensis genes, designed to safeguard against particular pests. Furthermore, the impact of *GM crop* cultivation on sustainable agricultural practices and ecosystem resilience were evaluated and synthesized. Recommendations for future research include investigating long-term effects, enhancing monitoring techniques, and promoting interdisciplinary collaborations. Addressing knowledge gaps is crucial for informed policy-making to ensure the responsible cultivation of GM crops while preserving environmental integrity. Traditional agricultural methods utilize various techniques like crossbreeding, soil preparation, pest control, and water management to optimize crop yield. *Genetically modified (GM) crops* offer a more targeted and efficient approach by directly manipulating crop genetics, bypassing time-consuming conventional breeding. *GM* allows for the incorporation of diverse genetic material beyond species boundaries, addressing inherent crop limitations and enhancing adaptability to environmental challenges. According to our assessment and contemporary studies on the effects of *GM crops,* it's evident that *Bt crops*, much like any recent crop protection innovations in agriculture, present prospective advantages for farmers. Genome editing in plants for resistance against insect pests for crop improvement (Figure 3). Although there are evident advantages to farmers from the implementation of *Bt crops* and similar innovative agricultural technologies, there is a spectrum of potential risks associated with them that are contingent upon the specific crop in question. Scientists and regulators grapple with conflicting demands about *GM crops*. Farmers want higher yields with fewer pesticides, consumers seek better quality food and a cleaner environment, while policymakers aim for food security and sustainable crop methods. The *GM crop* debate extends beyond crops, involving agriculture, environment, trade, and poverty. While GM crops are more accepted in the USA, Canada, Argentina, and China, European reluctance is fueled by media fears, differentiation between food and non-food *GM crops*, distrust in stakeholders, and clashes between local values and global economic objectives. After a decade of global *GM crop* cultivation, there's a pressing need for independent research, clearer guidelines, and post-release monitoring. Differing opinions exist regarding the cautious handling of widespread adoption of *GM crops*, highlighting the necessity for careful implementation involving comprehensive risk evaluation and continuous surveillance. Specialists stress the importance of comprehending the risks associated with *GM crops* within the larger agricultural framework and involving various stakeholders to assess their localized effects. Our stance aligns with the viewpoint expressed by *FAO Director-General*, Ms. Louise Fresco, who recently emphasized the growing significance of monitoring both the advantages and potential risks of cultivated *GM crops*, particularly in the case of pest-resistant varieties, given their significant expansion in commercial cultivation. In certain countries, there are ongoing discussions regarding the establishment of baselines for comparing genetically modified *(GM) crops*. These discussions have emerged in response to concerns about the significant negative impact on the environment caused by certain conventional agricultural practices. The UK, with more than 70% of its land dedicated to farming activities, has experienced substantial declines in specific types of birds inhabiting farmland over the last three decades. In 2015, The Environmental Protection Agency (EPA), Food and Drug Administration (FDA), and The United States Department of Agriculture (USDA) began an effort to modernize the regulatory system for biotechnology products to accomplish three tasks: (1) clarify the current roles and responsibilities of (EPA), FDA, and USDA in the regulatory process; (2) develop a long-term strategy to ensure that the Federal regulatory system is equipped to efficiently assess the risks, if any, of the future products of biotechnology; and (3) commission an expert analysis of the future landscape of biotechnology products. The Update to the Coordinated Framework for the Regulation of Biotechnology was released on January 4, 20172 ,representing the first time in more than 20 years that the Federal government has produced a comprehensive summary of the roles and responsibilities of the three principal regulatory agencies with respect to regulating biotechnology products [37]. Evaluating the ecological influence of genetically modified crops on an individual basis is a beneficial approach for regulatory considerations. However, this method may overlook potential indirect consequences that could arise from introducing specific crop varieties. Indiscriminate use of genetically modified crops may lead to monoculture and excessive manipulation of agricultural ecosystems. This focus on maximizing productivity could compromise diverse wildlife food chains, including insects, seeds, weeds, and birds, as well as the preservation of various habitats. Two primary concerns associated with transgenic crop plants are the possibility of unforeseen consequences within the intended group, like potential negative impacts on consumer health or the emergence of resistance in targeted pests or pathogens. Additionally, there's the risk of unintended effects on non-target populations, resulting in variation in regional biodiversity associated with the transgenic plant or its genetic material. The environmental impacts extend beyond genetically modified crops. A significant challenge in the future is managing their introduction and widespread acceptance while prioritizing environmental welfare. Genetically modified crops offer advantages in addressing food insecurity and malnutrition by enhancing nutritional content, withstanding herbicides, resisting environmental challenges, and prolonging produce shelf life, benefiting farmers. While not a complete solution, these crops hold promise in ensuring food security and reducing poverty by increasing crop yield, especially in challenging climates. Encouraging their integration with agricultural practices promoting crop diversity, efficient rotation, soil fertility, and biodiversity preservation is crucial. Incentives should aim to minimize the environmental impact of agriculture. Recent research indicates that genetically modified (GM) crops have both advantageous and disadvantageous impacts on the environment.

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.تأثيرات البيئة المرتبطة بزراعة المحاصيل المعدلة وراثياً ـ استعراض

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ملخص: يقوم هذا الاستعراض بدراسة نقدية لتأثيرات البيئة المرتبطة بزراعة المحاصيل المعدلة وراثياً (GM)، متناولًا الجدل الشديد المحيط بتأثيراتها المحتملة. من خلال تجميع الأدبيات الحالية من خلال نهج منهجي يشمل الدراسات المحكمة، وتحليلات البيانات الشاملة، والتقارير العلمية، يهدف الدراسة إلى توفير فهم متنوع للعواقب البيئية لزراعة المحاصيل المعدلة وراثياً. الهدف الرئيسي هو إعلام صانعي السياسات والباحثين والمعنيين بالأمر، مع التأكيد على ضرورة مراقبة موحدة ومنهجية للأبحاث. يتم التركيز على تأثيرات البيئة متعددة الأوجه، حيث يظهر النتائج الإيجابية مثل تقليل استخدام المبيدات، وتحسين الحفاظ على التربة، وتقليل انبعاثات غازات الاحتباس الحراري. ومع ذلك، تثير المخاوف بشأن التأثيرات غير المقصودة على الكائنات غير المستهدفة، وتدفق الجينات إلى الأنواع البرية، وظهور الأعشاب الضارة المقاومة للأعشاب. يقر الاستعراض بالتباين في نتائج الدراسات والمنهجيات، مما يشكل تحديات في استخلاص استنتاجات حاسمة بشأن التأثير العام. وتؤكد الختام على أهمية البحث المستمر لتقييم بشكل شامل الآثار البيئية لزراعة المحاصيل المعدلة وراثياً، مع التأكيد على ضرورة المراقبة الصارمة، والمنهجيات الموحدة، والتقييمات على المدى الطويل. ويشدد على أهمية التقييمات السياقية للحساب لتنوع الإعدادات الزراعية والنظم البيئية. يُوصى بإنشاء بروتوكولات موحدة لتقييم التأثير البيئي عبر مختلف النظم البيئية، بالإضافة إلى زيادة التعاون بين فرق البحث متعددة التخصصات وصانعي السياسات ومعنيي القطاع الزراعي لتعزيز الممارسات المستدامة. وتشمل اتجاهات البحث المستقبلية التركيز على المراقبة على المدى الطويل، وتقييم المخاطر القوي، وتطوير التكنولوجيات المبتكرة لتعظيم فوائد المحاصيل المعدلة وراثياً مع التقليل من الآثار السلبية المحتملة.

.كلمات مفتاحية: تنوع الحياة؛ المحاصيل المعدلة وراثياً؛ مراقبة؛ توصيات سياسية؛ الآثار البيئية المحتملة؛ تقييم المخاطر؛ الاستدامة