Critical Examination of Potentials and Pitfalls of Genetically Modified Foods

ABSTRACT

Although genetic engineering has revolutionised plant development through genetic modification (GM), humans have used artificial selection for thousands of years. Recombinant DNA technology was used to generate GM crops with better nutrition, insect and herbicide resistance, and other features. Successful examples of how GM crops can be used to solve agricultural issues include Indian cotton and Australian canola. Before GM crops are released, regulatory agencies such as the European Food Safety Authority and the U.S. EPA make sure they are safe. As demonstrated by Bt corn and cotton, GM crops can improve sustainability, food security, and the usage of pesticides. Nonetheless, worries regarding societal acceptance, environmental effects, and food safety continue. This analysis highlights the promise for sustainable, future agricultural practices by examining the current status of GM crop research, regulatory regulations, and hurdles.It seeks to foster consumer trust while assisting in the making of well-informed decisions regarding the role of GM crops in resolving global food issues.

Keywords: Genetically modified crops; biotechnology; food security; government regulation; global concern.

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1. INTRODUCTION

A genetically modified organism is an alteration of a specific gene in which genetic material has been cut or altered to include a strand of DNA from another organism and the collection of DNA parts is independent of their actual origin. Genetically modified food is a better and modified version of normal crops. According to scientists, compared to organically grown crops that have not undergone genetic modification, genetically modified food is safer for human health and offers more vitamins and minerals (World Health Organization, 2016).To know genetic material, the functioning of genes, and modification of genes in crops this technology was extensively used by scientists and researchers in the late 20th century. Basic genetically modified crops that cotton, maize, and soybean have been in use by this technology for over 25 years. Rapid growth has been observed in genetically modified crop production technology. Genetically modified crops are better resistant and endowed with the primacy of herbicide-resistant, pesticide-resistant, droughtresistant, etc. Scientists are aiming ahead to have an edge in decreasing chemical use on farms to preserve productivity but this goal has not been accomplished as there is a resistant development in insects and pests. It took over 25 years for golden rice to get the patent, golden rice is a good source of vitamin A and beta-carotene as it is a genetically modified variety of rice (Nirenburg et al., 1963).People demandlabelling of genetically modified products and to provide them with the proper concern of it. The bacterial genes that have been added to the genomes of the GM crops currently on the market encode various beneficial functions, such as resistance to pesticides or herbicides, rise in output, resilience to drought, flooding resistivity, etc. Still, in a few parts of the country, people are not in favour of the use of genetically modified crops as they are in the habit of using organically grown crops only. So there is an increased need to advertise and commercialize genetically modified food and crops to reach out to Indian farmers and the public to give relevant information and advantages of this technology. Scientists are continuing the growth of transgenic crops with modern breeding technology and the growing of genetically modified crops (Alexedratos,2012). Scientists have stated that there is no harm to human consumption of such crops as researchers have seen over the past 20 years, still, it remains a concern for scientists as people resist genetically modified crops. Currently, genetically modified technology and the growth of transgenic crops are in high demand, being as source of income for many big firms and companies. Adding its contribution to the worldwide economy and investors are investing crippling amounts for these to grow on a large scale (Schmidt et al., 2011). However, researchers continue to edit the genome of existing crops to transform them into an improved variety (Cong et al., 2013). Several states have attempted to enact laws requiring labelling food goods containing genetically modified organisms (GMO's) in response to popular disapproval of the technology (Ran et al.,2013). These laws also aim to commercialize genetically modified crops in India and facilitate the dissemination of biotechnology research to Indian farmers. A large number of private businesses also made significant investments in the study and creation of transgenic crops. Now, GMO's are undoubtedly an intrinsic part of many agriculture-based commodities in every corner of the world, adding billions of dollars each year to the global economy, and being a key income source for developed and developing countries including India (Brookes&Barfoot, 2013). The genetically modified crop pipeline has currently spread to include a wider range of fruits, vegetables, and cereals, including lettuce, strawberries, eggplant, sugarcane, rice, wheat, carrots, and so on. Its intended applications include boosting the bio-production of vaccines, providing nutrients for animal feed, and conferring salinity and drought-resistant traits to plants so they can grow in unfavourable environments and climates. Genetically modified crops have proven advantageous for the environment and the economy ever since they were commercialized. Moreover, it has been observed that GM crops lessen their effects on the ecosystem and ecology, which improves the diversity of species. Thus, it should come as no surprise that the majority of environmentalists worldwide, growers, and agricultural scientists have praised genetically modified crops. However, developments in genetically modified crops have prompted serious concerns about their efficacy and safety. The positive impacts of genetically modified seeds have been severely weakened by issues with human health and insect resistance plaguing the GM seed industry.

2. HISTORY OF GENETICALLY MODIFIED CROPS

India is facing an impending food catastrophe. Pests and illnesses already cost farmers in the nation about Rs. 49,800 crores ($4.89 billion) annually (Avery et al., 1944). The issue is getting worse due to droughts and a lack of irrigation infrastructure. According to UN estimates, the country's population, which is currently1.79 billion will increase to 1.99 billion by 2050, meaning that the problem might only get worse. Agricultural biotechnology holds enormous promise in light of India's high rates of poverty, hunger, and malnourishment as well as its low agricultural output (Oliver, 2014). It is practically hard to feed a billion or more people with traditional agricultural techniques. India possesses abundant bio-resources, and biotechnology presents prospects for transforming biological wealth into economic prosperity, thus generating fresh job prospects on a socially sustainable basis(Sanford,1990; Shubham et al., 2022).Early results and the impact of genetically modified crops made researchers more curious about growing and researching genetically modified crops, making this concept more widespread and even proving to be a better version of normal crops grown under conventional breeding methods (Cohen et al.,1973). Due to these early results, more research and development were spurred, which resulted in the widespread use of GM crops bearing a variety of advantageous features only (Bawa et al., 2015). The quick uptake of genetically modified foods in several nations demonstrated their potential to transform agriculture, but it also spurred discussions about their safety, effects on the environment, and moral implications, setting the stage for ongoing conversations that still shape the field today (Ray et al., 2012). The world's GM crop area reached a record 206.3 million hectares in 2023, up 1.9% from the year before (Nirenburg et al., 1963). Eleven distinct genetically modified crops were grown in 27 different nations. Soybeans were the most extensively planted crop, covering 100.9 million hectares, for the first time, this crop had ever exceeded 100 million hectares (Bevan, 1983). After soybeans, 69.3 million hectares were planted in maize, while 24.1 million hectares were planted in corn. Since GM crops were first introduced in 1996, the number of countries cultivating them has fluctuated due to many causes, including the ban on GM maize production in numerous European countries and the end of GM corn planting in Burkina Faso nations have routinely grown genetically modified crops since 2020; this Fig.1 was also attained in 2015 (Brookes, 2013).

Overview and history: Cracks in the approval process for GM processed foods.

Genetically modified crops are those crops whose genetic material has been modified and genetically engineered by using modern-day techniques to improve crop varieties by altering the genome or replacing the genetic material of existing crops with new genetic material (Table 3) (Cong et al., 2013). In easier words editing or replacing genetic material, it could not happen naturally. The inserted gene is known as a transgenic gene and a method such as agro-bacterium-mediated transfer is used to transfer nucleic content (Ranet al.,2013). In India Rice, cotton, maize, and soybean are initial sources of producing more crop varieties by genetically modifying these crops (DeMayo &Spencer 2014). This technique is independent of natural mating and swaps with the method of alternation of genetic material to induce more resistance in new crop varieties (Brookes et al., 2014). Genetic modification is restricted only to crops, /species and organisms of unrelated species can be formed with DNA alternation and genetic modification techniques. Modification using biotechnology can best define genetically modified organisms or genetically modified crops (James et al., 2013).

With 76.0% of the world's total cotton acreage, cotton has the highest rate of GM% utilisation, followed by soybeans (72.4%), maize (34.0%), and canola (24.0%). The pace of worldwide adoption rapidly declines after this (Tables 1, 2) (Fig. 1). Since 1989, the Ministry of Environment, Forests, and Climate Change's (MoEF&CC) Genetic Engineering Appraisal Committee (GEAC) has been in charge of authorizing the commercial production of genetically modified crops and the production, importation, and distribution of processed foods using genetically modified ingredients. Bt cotton has been authorized for cultivation thus far. The GEAC sought to limit its authority to approve living modified organisms (LMOs) following the passage of the Food Safety and Standards Act in 2006 and transfer the responsibility for approving processed foods to the FSSAI, for which a notification was also issued in 2007. In response, the MoEF&CC was asked by the Ministry of Health and Family Welfare (MoHFW) that same year to keep regulating processed foods until the FSSAI was prepared to do so in a methodical way. Despite Section 22 of the Food Safety and Standards Act, 2006 (FSS Act), which states that genetically modified foods cannot be produced, sold, distributed, or imported until the FSSAI gives its approval, the notification was kept in a limbo until 2016, leaving the GEAC in charge of processing food approvals and the FSSAI with no practical accountability. In the meanwhile, the Legal Metrology (Packaged Commodities) Rules, 2011 were changed in 2013 to require that the term "GM" be shown on the main display panel of any package containing genetically modified foods. This regulation was in conflict with India's ban on genetically modified foods and actually gave the impression that they were acceptable. By requiring GM food labels, the FSSAI's new proposed labelling policy from April 2018 seeks to address the problem.

Table 1. Global adoption of GM crops

Crops	GM Area (Ha m.)	Total Area (Ha m.)	% Share
Cotton	24.1	31.7	76
Soybean	100.9	139.4	72.4
Maize	69.3	203.5	34
Canola	10.2	42.5	24
Sugar beet	0.5	4.3	11
Alfalfa	1.2	35	3.4
Sugarcane	0.06	26.1	0.2
Brinjal	0.003	1.9	0.2
Rice	0.05	165.1	0.03
Wheat	0.04	222.7	0.02

(Source: Global GM Crop Area Review, 2024)

Table 2. Some of the important GM crops

Sr. No.	Name of the crop	Gene	Name of gene	Released by	Status
1.	Potato	Fungal resistance	Rb gene	CPRI, Shiml a	Event selection trials
2.	Wheat	Salt tolerant	Osnhx 1 gene	Mahyco	Event selection trials
3.	Rice	Water use efficiency	it gene	Mahyco	Event selection trials
4.	Rice	Salt tolerant	Osnhx 1 gene	Mahyco	Selection trials
5.	Brinjal	Insect resistance	Cry 1 Fa 1 gene	Rasi seeds	Selection trials
6.	Cotton	Insect resistance	cp4epsps gene	ICAR-Nagpur	Confined field trials
7.	Cotton	Herbicide Resistance	cp4epsps gene	Mahyco	Confined field
8.	Cauliflower	Insect resistance	Event CFE4	Sungro seeds	Confined field trials
9.	Maize	Herbicide resistance	Cp4epsps	Metahelix	Confirmed field trials

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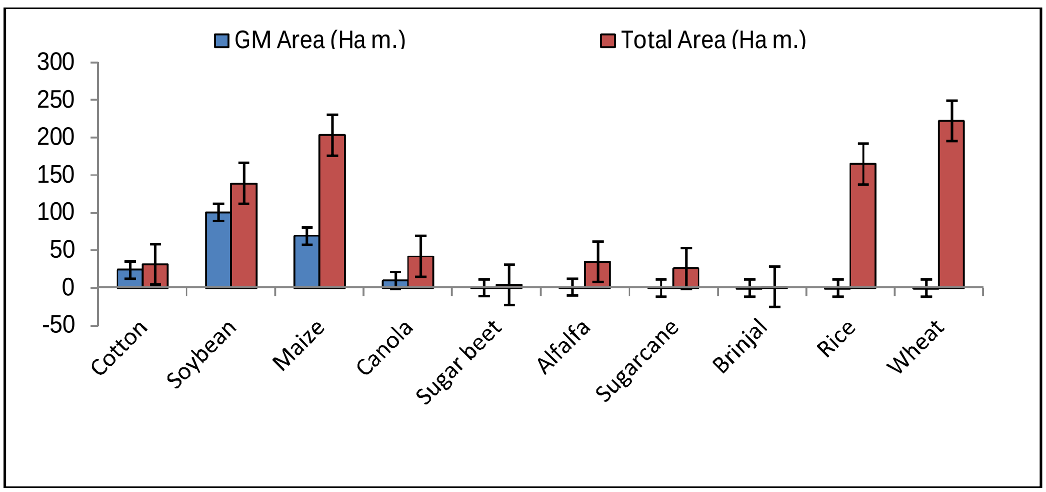

Fig.1. Global adoption of GM crops (%)

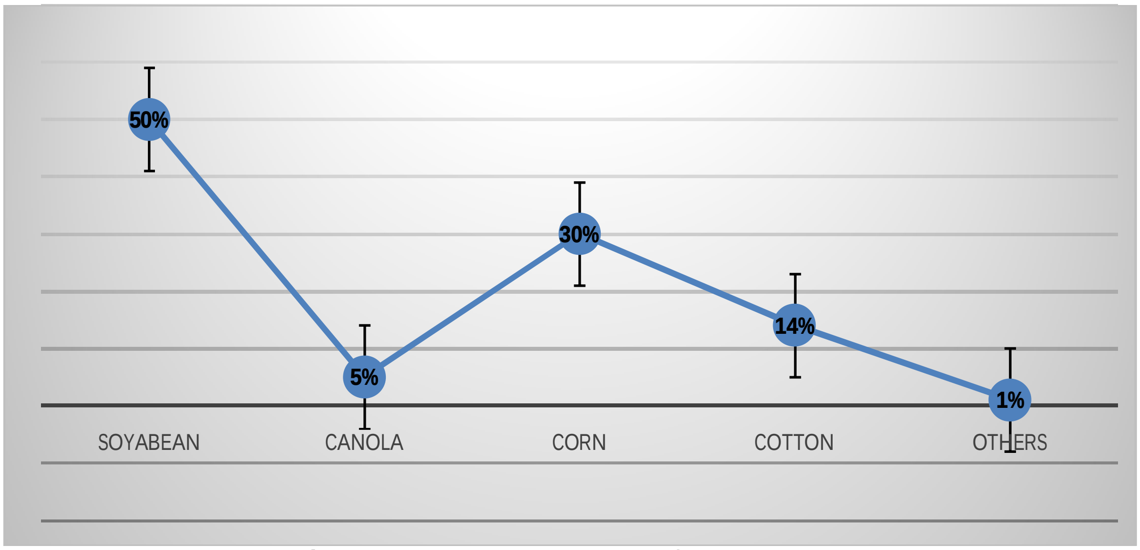

Fig. 2. GM crops as a per cent of total GM area

Need for genetically modified crops: There is a need for qualitative and quantitative traits in improved varieties to meet population demand and nutritive value (Shell et al., 1977). According to current reports, there is less yield increase than the actual yield to meet the demands of the increasing population at annual rates (Rizzi et al., 2012).

1) Impediments of conventional and modern breeding methods

In 2023, the global area under GM crops increased 1.9 per cent over the previous year to reach 206.3 million hectares, a new record area. 27 countries cultivated a range of 11 different GM crops, with soybean the most widely planted at 100.9 million hectares; the first time the crop has exceeded 100 million hectares. Following soybean is maize at 69.3 million hectares, and cotton at 24.1 million hectares (Table 3). Conventional and modern breeding methods are dependent on genetic material and sexual crossing which could be a long process to get desirable characters (Schmidt et al., 2008). The breeding method approach would take long years to express the desired traits, though it needs to be backcrossed again by the backcross method to get improved varieties (Kramkowska et al., 2013). Moreover, such methods strongly rely on sexual crossing which would further limit it if prerequisite breeding strategies are not performed well. Genetic modification will involve new modern technologies such as rays or variations to induce new mutation variants and changes to add new varieties and traits to the agricultural field (Oakes et al.,2013).Some more facts involve that conventional and modern breeding methods have limited genetic diversity, so developing crops with complex traits won't be worthwhile (Oake et al.,1991). Even using conventional breeding methods would make crops more susceptible to stresses, as well as while crossing some unwanted traits may also get relocated which would hurt newly growing varieties (Nicolia et al., 2014). Taking all the pros and cons collectively, the inception of biological technologies and the emergence of genetically modified food becomes one such option to overcome the limitations of conventional breeding and a positive approach to meet agricultural demands worldwide.

In addition to highlighting the use and scope and scope of genetically modified crops in various countries including India, offers background information from various website sources for this review article. I used website sources which offer perceptive information about the contribution of transgenic crops in influencing changes in agriculture land use and amount of percentage share

Table 3. GM crops area by leading countries 2023

Country	GM Area (Ha m.)	% Change	% Share
USA	74.4	-0.4	36.1
Brazil	66.9	5.9	32.4

Argentina	23.1	-1.4	11.2
India	12.1	-2.3	5.9
Canada	11.5	1.5	5.6
Paraguay	4.3	8.2	2.1
South Africa	3.3	-7.9	1.6
China	2.8	33.3	1.3
Pakistan	2.3	7.0	1.1
Bolivia	1.5	-1.8	0.7
Others	4.1		2.0

2) Thriving of population

The expansion of population is one such reason to enhance the growth of genetically modified crops as according to a census report, the world population is said to expand with an increment of 83 million people. According to estimated predictions for the future, the population will be at its peak hitting 8.5 billion in 2030 and around 9.8 billion in 2049-50 (Chandler&Dunwell, 2008; Shubham et al., 2023). More the population rises more food would be required to fulfil individual needs, which contributes a major concern not only in the growth of agricultural land but also the majority in genetically modified crops that would give better-improved crops in less time (Hare &Chua,2002). One of the debate points is whether to increase cultivable crops on agricultural lands from time to time (Schafer et al.,2011). However, this is an intimidating task that requires adding crop genetics in the agrarian sector.

3) Decrease in area of productive land

Food and Agriculture of the United Nations organization estimated that the amount cultivated or arable land will drop down for food production per person which will be around 0.242 ha to 0.18 ha by 2050 which may also lead to malnutrition (Aggarwal et al.,2012). Alternatively adding more cultivable land would cost more as it will require inputs, fertilizers, heavy farm machinery, and labour and of course, will consume much of the time (Reichman et al., 2006). Productive or arable land has been reduced due to factors like land degradation, deforestation, changes in climate, exploitation of land, and yet more (Baulcombeet al., 2014). So decrease in land limits production for cultivation crops and growing crops in the old and organic way will not be able to meet food requirements globally (Gibson et al.,2013). So to achieve food security and avoid undernourishment of the population it's important to use the technology of crop genetics(Werth et al.,2013).

4) Potential edges of genetically modified crops

a) Products for restorative purposes

Restorative or therapeutic refers to the process of healing which could surely be achieved by genetic engineering techniques (Barefoot et al., 2013). Such techniques make it possible for bacterial antigens to express themselves in edible portions of food which serve as a good source of vitamins, and minerals and even have the potential to provoke good immune systems and oral vaccines in human bodies(Chaturvedi, 2012). Transgenic food made by genetically modified techniques even serves as potential frontiers against infection. Crops such as maize, soybean, rice, etc are under research to check if they are effective against disease and infections and would be able to replace heavy doses of medicines and injections (Choudhary&Gaur, 2010).

b) Agronomic convenience

Food crop productions increased by more than 370 million tons between 1996 and 2012. In the United States, GM crops are responsible for one-seventh of the surge in yield. More than 300 million acres of conventional crops would have beenrequired to obtain an equivalent improvement in yield as provided by GM crops (Gheyesen et al., 2014). These extra 300 million acres would have to be cleared tropical forests or areas that needed more irrigation or fertilizer (Indian Express, 2017). The world would be seriously stressed ecologically and environmentally by such land conversion. Similar findings were reached in a paper by Brookes and Barfoot: they estimated that during the years 1996-2013, biotechnology contributed to an increase in worldwide soybean production of 138 million tons, 274 million tonnes of cotton lint, 8 million tons of canola, and 274 million tons of grain was produced (Morse & Mannion, 2008)

c) Refinement in food processing

Genetically modified crops have contributed well to improving food industries. Genes resistant to herbicides, insects, drought, stress, and many other conditions have been produced, which is a remarkable accomplishment (Mathur et al., 2017). For instance, the Bt gene from Bacillus thuringiensis issued in various crops such as maize, and cotton to reduce chemical insecticides. Disease-resistant genes help crops to resist diseases like bacteria, fungi etc. Take the example of inducing barley Mo against powdery mildew, Lr34 against leaf rust etc., (Mishra & Shukla, 2013). Pro-vitamin A beta-carotene in golden rice is a patent achievement in the enhancement of nutritional content and vitamin A in rice. By delaying ripening and improving fruit quality, flavrsavr in tomatoes has been beneficial in improving the shelf life and quality genes.

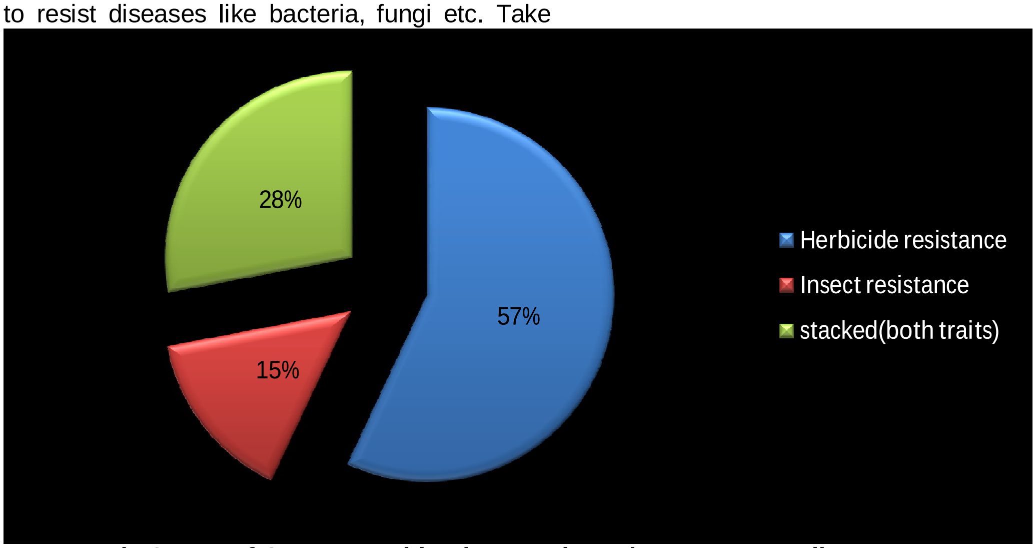

Fig 3. Use of GM crops with advances in resistances according to percentage.

d) Financial gain

Farm income from genetically modified produce increased globally to $116 billion between 2006 and 2012, nearly tripling the amount from the preceding ten years. More than 40 per cent of economic gain came from production by improved genetic varieties which were highly resistant to the losses occurring concerning conventional crops. Costs were cut down in terms of using herbicides, chemicals, insecticides and even agricultural land which would have required a lot of input including farm machinery (Turnbull et al., 2021).

e) Adaption of chemical constituents in food

Many reasons and causes are targeted to enhance the growth of genetically modified crops (Zhang et al., 2016). Still among them, the main and specific cause that is highly targeted is to add health value and certain nutritive substances that have high healing and pro-health value to serve as oral vaccines. One outstanding example is 'Golden rice' which is been genetically modified and altered to provide more healthy and nutritious benefits (Parwez, 2013). Genetic modification is not restricted only to rice crops but also has given amazing results in the case of potatoes. Polysaccharides are often formed by two forms of starch amylopectin and amylose which are the main constituents of making polysaccharides in potatoes. GSSB (Granule bound starch synthase), is one of the enzymes needed to synthesize starch. The transgenic procedure entails introducing an extra copy of the GSSB coding gene in the potato by process of co-expression and this modified variety of potato was termed 'Amflora'(Reuters,2015).

f) Potential risks of genetically modified crops

The negative consequences of GM crops on human health and ecological safety are the major topic of interrogation in the GM food debate as the scientific community is not able to illustrate biological techniques used in GM crop which increases worries and consumer anxiety (Bawa and Kumar, 2013). Also, improper distribution of genetically modified including the mentality of naturally growing crop by conventional method is better than present-day technology of GM crops which is set ethical thinking among the population (Nayer et al.,2012). The majority of hesitation is about the suitability of GM food evaluation.

Environmental pitfalls on the path of GMO crops cultivation:

1. Turmoil of the food web

Alternatively, there is more concern regarding pests. An additional concern is the potential for insect-resistant plants to increase the quantity of small pests while decreasing the quantity of larger pests (Food and Agriculture, 2017).In simpler words, it is reverting back oppositely. The prospect here is that new, unafraid species may replace the pests that the modified plants are discouraging (Fig.3) (Bebber et al., 2014). This change might then cause a widespread upheaval in the food chain, resulting in new predators for the newly discovered bug species, and so on, all the way to the top of the food chain. Alternatively, the disturbance might occur oppositely, with pesticide residues or insect-resistant plants potentially having negative impacts on nearby soil-dwelling creatures like fungi and bacteria (Ordonez &Seidh, 2015).

2) Antibiotic resistance

Good bacteria or bad bacteria often have the capability of disrupting certain useful genes which is a major concern in the medical sciences of genetically modified crops (Barfoot etal.,2012). Over therapeutic use of such genes would lead to antibiotic resistance in various medicines (Chen et al.,2013). Antibiotics are commonly used as selection markers in genetic modification to discriminate between successfully transformed bacteria and those that did not get the transfecting genes. Genetically modifying an organism may introduce antibioticresistance genes into the micro-flora of the human and animal gastrointestinal tracts, as well as pathogenic bacteria in the food consumed by consumers. Bacteria, both good and bad, can transfer useful genes, such as those that protect them from antibiotics, horizontally (Zdziarski et al., 2014). Excess production of genetically modified crops will lead to resistance in pests, diseases which would badly impact agriculture production. Crops are been genetically modified and are not naturally grown under environmental conditions, which could have a negative health impact on consumers. The trade and the environment are put at risk by transgenic crops in addition to farmers. Genetic modification discontinues natural selection, there could be a significant peril for ecosystems and biodiversity. It raises the worth of cultivation and more bends towards the market of farming which means that proper marketing is needed for genetically modified crops which would require high costs including elevated price of cultivation. Because gene assembly affects natural selection and the flow of genes naturally, there is a significant risk that ecosystems and biodiversity may be disrupted (Dubek et al., 2004).

a) Nutritional Enhancement

Nutritional Enhancement the process of bio-fortifying crops, like Golden Rice, to boost their nutritional value by adding more vitamin A. Developing crops that can withstand abiotic challenges such as drought, salt, and severe temperatures is known as climate resilience.

b) Insect Resistance

Producing toxins that are toxic to particular insects, crops with this trait lessen the need for chemical pesticides. GM crops exhibit resistance against bacteria, fungus, and viruses.

c) Herbicide Tolerance

Herbicide tolerance crops that have been genetically altered to resist particular herbicides, enabling farmers to manage weeds without endangering the crop.

Prospects of genetically modified crops:

a. By using the genetic modification techniques, future goals of transgenic crops in case of disease resistance, herbicide resistance, and biotic, abiotic stress resistant crops can be achievable (Fig.3).
b. Nutritional modification in crops by deletion and addition of DNA strands.
c. Modification of essential amino acids that can't be modified by humans but can be accomplished by genetic modification technique (Seralini et al., 2014).
d. To promote public trust and environmental safety for the safe adoption and commercialization of genetically modified agriculture, the development of regulatory frameworks and bioengineering agreements in India is essential.
e. A wider level of growth in the case of genetically modified crops can be attained by public views and open communication about the advantages and safety of GM crops which could lead to wider affirmation and unification into Indian agriculture.
f. GM crops can lead India favourably in the global agricultural market, which could help

to gain international recognition of Indian agriculture which could potentially facilitate the country's economy (Bucchini et al., 2002).

3. CONCLUSION

Several of the present difficulties facing commercial agriculture can be lessened by GM crops. According to market trends, they are among the most inventive and rapidly expanding worldwide sectors, benefiting not only growers but also consumers and the economies of large nations. Still, the agricultural industry and science community must invest in improved regulation and science communication to address fraudulent studies and false facts. Stricter regulations, worldwide risk mitigation strategies, government agriculture agencies' monitoring and implementation, and communication with growers can all help prevent infections and major genetically modified technologies and ensure a higher level of acceptability. Growth in bio-formulation and stress tolerance, along with significant advancements in precision gene-integration technologies, are expected to make genetically modified crops more profitable and productive in commercial agriculture, facilitating more seamless advancements in the Indian economic sector of Agriculture. Problems concerned with nutrition and food security transgenic crops have many benefits to address such problems. An increase in nutritional content, resistance to abiotic stresses and a longer life of fruit can help growers find a market with good financial growth in terms of selling more fruit crops. Despite the lack of strong scientific evidence to support the safety of GM foods, the debate over genetically modified crops and whether they are safe or not will never stop. Remarkably few public sector intuitions expressed their concerns about genetically modified foods. Given India's pressing need, we cannot stop this effort, despite the country lacking the fundamental infrastructure and strict regulations needed for GM crop research and risk assessment. India should ideally keep researching genetically modified crops and deregulating them, developing the necessary infrastructure, creating strict bio-safety regulations, and creating marketing rules. There is an urgent need to create an online portal and one window system for the assessment, control, regulation, and approval of genetically modified agriculture (GM crops), even though portals like GEAC, IGMORIS (Indian GMO Research Information System) and biosafety Financial Institution fulfil their roles in evaluating bio-safety and their regulation of GM crops. Extensively, there are differences in regulatory actions to genetically modified crops. Although the USA and Brazil have adopted TGM crops widely, while European Union imposes strict restrictions. Taking over the technology of CRISPR TECHNOLOGY genetically engineered crops have more advances. In order to feed a growing world population under climate stress, genetically modified foods have changed agriculture by providing ways to increase crop yields, decrease the use of pesticides, and boost nutritional value. Despite their advantages, genetically modified foods are controversial due to safety issues, environmental hazards, moral dilemmas, and differing public opinion.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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