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Review article

The future of plant food security lies in food biotechnology

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A B S T R A C T

The restriction on the development of agricultural fields due to the population growth and the conversion of arable land to residential one has caused the failure in the production of macular crops. Also, the increase in greenhouse gases especially resulting from livestock on farms and also urban life and the resulting climate change; have posed major environmental challenges to almost all human activities over the years. Currently, modern biotechnology can be used for sustainable development in agricultural productivity and related industries to solve human problems in diseases, poverty, pollution, and the current food crisis. Because the traditional systems can no longer meet the world's food needs. Therefore, there is an urgent need to use modern biotechnology to accelerate the development of executive programs.

Keywords: Agriculture; Biotechnology; Food security; Hunger; Resources

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1. Introduction

The world population growth has restricted arable lands and intensified human hunger and air pollution through greenhouse gases emission via greater reliance on cars resulting from urban life (Ali et al., 2021). This problem can be solved mainly through the use of biotechnology.

Food Biotechnology with the effective role of various organisms (microorganisms, plant and animal originated organs) is an important branch in modern food and feed industries especially in the field of food additives; new formulated foods and value added nutritious products for human being and animal feeding with increased shelf life and reduced food wastes (Hamdan et al., 2022).

Food Biotechnology can be applied in: 1) Genetically modified (GM) foods: Genetically modified foods such as engineered soybean, tomato, maize, cotton, potato and rice are some examples for the purposes of increasing quality and quantity attributes with the low production costs with the considering the health risks concerns (Hamdan et al., 2022); 2) Enzyme technology and enhance enzyme activity via gene engineering: Increasing activity in alpha-amylase for baking, brewing, distilling, and starch industries, renin for cheese products, protease for fish, meat, vegetables and dairy technologies, lipase for fat and oil industries; are some examples of enzyme applications in food and feed industries (Enitan-Folami & Swalaha, 2020).

2. *The importance of biotechnology for food and agriculture*

It is estimated that the world population will increase to 8.5 billion by 2030 and 9.7 billion by 2050 (Zhang et al., 2016; Baghbani-Arani et al., 2021). Because arable land, water resources, environmental conditions, and biofuels are not available in sufficient quantities, a parallel increase in food production seems necessary to feed the growing world population in the coming years. As an example, in the EU, 22 million farmers and agricultural workers in the agricultural and food sectors, as one of the most important economic sectors, provide food resources to more than 500 million Europeans (Hundleby et al., 2019) which in the future will be insufficient. Therefore, one way to ensure food security for the future population is the development of transgenic products (Pratheesh et al., 2020). Thus, several factors encourage farmers to use genetically modified seeds, including an average 22% increase in crop yields and a 39% reduction in pesticide costs,

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as well as a 68% increase in profits from biotech products (Baghbani-Arani et al., 2021). Climate change, on the other hand, has been a major challenge to almost all human activities for years. Moreover, ever-increasing climate change may negatively affect global food security (Seid & Andualem, 2021). Thus, wheat productivity is threatened by global climate change. In several parts of northwestern Europe, a decline in disease resistance, especially wheat rust, has been observed during the wheat growing season (Miedaner & Jurosze, 2021). Thereby, it will be important in the future to increase crop stability and disease resistance. Also, the majority of research should be focused on the effects of heat stress and drought on disease resistance responses. The geographic distribution of the plant, seasonal phenology (e.g., the coincidence of pathogenic life cycle events with host plant growth stages and/or antagonists/natural synergies) may be due to climate change (Miedaner & Jurosze, 2021). Table 1 shows the changes in plant resistance in northwestern Europe.

Genetic engineering can dramatically improve crop yields without harming the environment. With limited land resources; transgenic technology has the best possible application to meet the challenges of global agriculture (Munaweera et al., 2022).

3. *Food health*

Research in agricultural biotechnology and transgenic crop production has progressed rapidly since its inception. Concerns about food systems arise from thinking about various factors that affect food production and distribution, such as the interplay of environmental, economic, and social factors. When there are limited sources it should be noted that the food chain extends to human consumption and that food security has dimensions that span the entire food system and require diverse but coherent technical, commercial, and political responses (Poole et al., 2021).

To maintain the health and sustainability of the food supply, especially for vulnerable populations, these factors should be considered as important references:

- Food must be nutritionally immune.
- Foods should be rich in nutrients at the time of consumption.
- The food should be consumed in sufficient quantity and continuously.

These references emphasize the downstream aspects of food security and the relationship between agricultural businesses and their customers (Maestre et al., 2017; Maestre & Poole, 2018). Many approaches have been used to increase food safety and nutrition. Various indicators have also been set. Food insecurity in urban slum households of India has been studied (Maitra, 2022).

Since the possibility of aflatoxin contamination in crops such as maize exists in several food chains of human and animal nutrition, significant systemic control requirements should be imposed. On the other hand, the implementation of international food safety standards in developing countries with weak knowledge and regulatory controls can create problems. The Partnership for Aflatoxin Control in Africa (PACA) developed and implemented a systemic approach to food safety in the maize sector in Kenya, funded by the Consultative Group for International Agricultural Research (CGIAR) in terms of Agriculture for Nutrition and Health Program (A4NH). The results showed that the application of aflatoxin testing methods in food along the entire maize value chain can increase the immunity of 10 million Kenyans to poisoning.

Table 1. Simulated fungal disease risks of winter wheat in Europe using plant disease models driven by climate change scenarios, usually downscaled to a regional level. Projections until 2050 are considered (Miedaner & Jurosze, 2021).

Disease (Pathogen)	Country (Region)	Change of disease risk[a]
Powdery mildew	Germany (NRW)	+
(*Blumeria graminis*)	Germany (LS)	–
	Germany (NRW)	+
	Germany (LS)	+
	Europe	+
Leaf rust	Luxemburg	+
(*Puccinia triticina*)	Scotland	+
	Poland	+
	France	+
	France	+
Yellow rust	Germany	+
(*Puccinia striiformis*)	Europe	+
Stem rust	NW Europe	+
(*Puccinia graminis*)	NW Europe, UK	+
Eyespot (*Oculimacula yallundae*)	Germany	o
Septoria tritici blotch	Germany	+
(*Zymoseptoria tritici*)	France	-
Septoria nodorum blotch (*Stagonospora nodorum*)	Germany	o
Tan spot	Germany (NRW)	o
(*Pyrenophora tritici-repentis*)	Germany (LS)	+
Fusarium head blight	Germany (NRW)	+
(*Fusarium* spp.)	Scotland	+
	UK	+

[a] Change of disease risk: – decrease, o unchanged, + increase, NRW = Northrhine-Westfalia, LS = Lower Saxony.

Table 2. European regulatory documents for the release of transgenic crops and the status of plant-modified plants (Turnbull et al., 2021).

Country	GM Commercial Cultivation	Legislation on Release of GM crops	Gene Editing Legislation
European Union	Only Spain and Portugal	Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC	Decision of the ECJ, but report and proposal requested from EU Commission (due 30 April 2021)
Norway	None	Gene Technology Act of 2 April 1993 No. 38 Relating to the Production and Use of Genetically Modified Organisms etc.	None, but proposal submitted
Russian Federation	None	Federal Law of 3 July 2016 No 358-FZ "On amendments to certain legislative acts of the Russian Federation concerning improvement of the state regulation in the sphere of genetic-engineering activities."	None
Switzerland	None	Federal Act on Non-Human Gene Technology (Gene Technology Act, GTA) of 21 March 2003 (Status as of 1 January 2018)	None

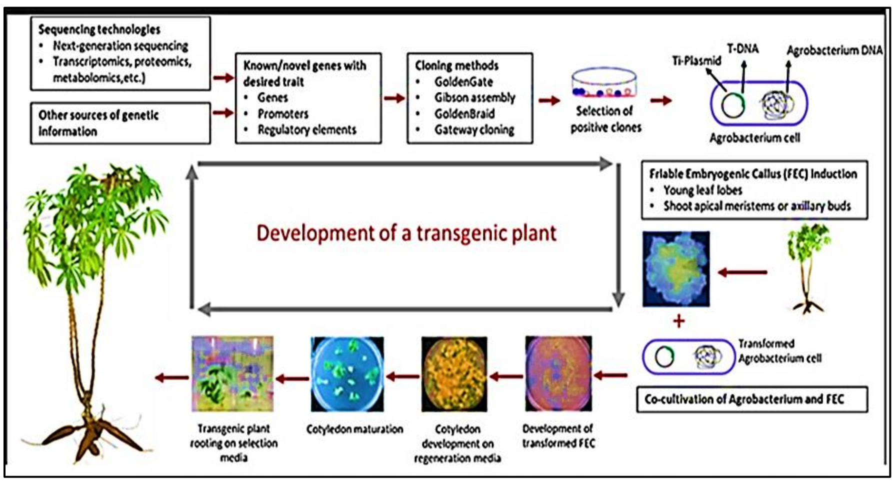

Fig. 1. Stages of development of gene transfer technology in plants (Anjanappa & Gruissem, 2021).

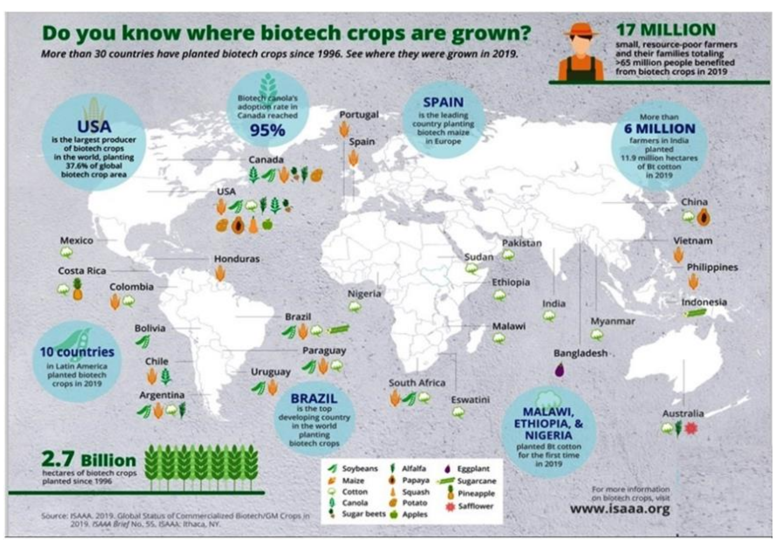

Fig. 2. Area under GMO cultivation in the world in 2018 (ISAAA, 2020).

Other scientific research demonstrates the importance of working with farmers and private sector companies in developing countries (Fisher et al., 2019; Pretari et al., 2019). As a result, developed countries are focusing on important research topics, such as gaining a better understanding of the food-political economy and the regulatory environment, and how governments choose the type of food and trade policies.

Conversely, biotechnology is one of the new and thunderous technologies in recent years in today's world, which is considered a suitable and powerful tool for sustainable development in the agricultural sector. Therefore, some countries in the world have already made long-term investments and set up plans to benefit from the myriad opportunities of this technology. Modern biotechnology, with its great potential to solve human problems such as diseases, poverty, hunger, environmental pollution, etc., can play a prominent role in influencing the health and economic development of society (Brookes & Barfoot, 2016).

4. *The prospects for the cultivation of Genetically Modified Organisms (GMO) in the world*

Since 1994, the cultivation of GMOs, including microorganisms, plants, and animals in which a different gene from other organisms has been artificially inserted into the genome in the laboratory, has been carried out under the slogan of eradicating poverty, reducing the use of pesticides and herbicides, and lowering food prices. So, variables in the literature of transgenic crop utilization in food industry; can be investigated on Knowledge, Attitude, Trust, Environmental concern, Ethical norms, Culture, Food Integrity and Health concern as important indicators (Badghan & Namdar, 2022).

Since the first transfer of DNA to plant cells by *Agrobacterium tumefaciens*, various methods have been developed that have led to rapid advances in molecular production approaches to produce a variety of products with novel traits. Today, gene transfer in the production of genetically engineered products is the fastest and most widely used technology in agriculture (Anjanappa & Gruissem, 2021) and its frequency is rapidly increasing. Sequencing of plant genomes and information from functional genomic data to understand gene function, as well as new developing methods of gene simulation and tissue culture, have accelerated trait improvement and increased the efficiency of crop production. These advances are now being welcomed to make crops more resilient to climate change and ensure their performance to feed a growing world population. Despite these successes, there are drawbacks in these methods as many plant species and plant genotypes are resistant or have low variability under regeneration conditions. Improvements can be achieved through the use of morphogenetic transcriptional modulators, but their widespread application is still in the experimental phase. Fig. 1 shows the stages of gene transfer technology in plants (Anjanappa & Gruissem, 2021).

Regarding the production of transgenic products in the world, as shown in Fig. 2, the United States is the largest producer of genetically modified products (ISAAA, 2020).

Currently, farmers grow biotech crops on approximately 190 million hectares, which is roughly equivalent to the total area of Mexico (ISAAA, 2020). The area under transgenic crops was less than two million hectares in 1996 and reached 191.7 million hectares in 2018 (Fig. 2). Soybean, com, cotton, and canola account for the largest area under transgenic crops. These plants usually contain either herbicide resistance genes (usually glyphosate herbicides) or the *Bacillus thuringiensis* gene, which produces an insecticide (against *Heliothis obsoleta* and *Spodoptera littoralis*) on all parts of the cotton plant (Pinheiro & Valicente, 2021).

Cotton is a major source of income for farmers around the world and an important product, especially for the textile industry. Bt (*Bacillus thuringiensis*) technology for cotton, introduced in 1996, was quickly accepted in many developed and developing countries because of its economic benefits. Because Bt, soil-dwelling bacterium that naturally produces a toxin that is fatal to certain herbivorous insects. The toxin produced by Bt has been used as an insecticide spray since the 1920s and is commonly used in organic farming (Encyclopaedia Britannica, 2022). In addition, by reducing chemical spraying, an environmentally friendly solution has been found to prevent crop losses due to insects and pests and to ensure farmers' health. Farmers' costs decrease due to reducing on-farm labour time and labour requirements, resulting in higher profitability. In addition, this technology increases the yield of cotton production. Farmers have made millions of dollars by reducing pesticide use. This study provides detailed information on the contribution of Bt cotton technology in the economies of the leading cotton-producing countries, its commercialization, and current crop transformation methods. Although it is debatable if this technology offers sustainability and long-term benefits. Currently, 15 countries, including India, China, and the United States, have deployed the technology. More countries are expected to join in the coming years (Tokel et al., 2021).

Another example is sorghum, a staple, and vital food and now the fifth most important cereal, a crop with a variety of uses as food, feed, fuel, and forage, and a model for the functional and genomic genetics of tropical plants. The rapid development of experimental technologies and highly efficient data processing has greatly accelerated sorghum genomics research in recent years. Sorghum, due to its genomic diversification, has been involved in the spread of thousands of available genetic resources in three directions and different genetic populations, including NAM, MAGIC, and mutant populations. The next step should be to develop a sorghum genome with proportional design to facilitate the development of a crop with excellent agricultural traits for various applications, as shown by the diversity of genes and alleles in important agronomic traits (Hao et al., 2021).

The size of the cultivated area and the spread of genetically modified crops in different countries depend on the laws of each country. For example, although transgenic soy has several benefits, the potential environmental risks of long-term consumption must be evaluated. In addition to the effects of transgenic crops on the ecological system, their effects on the soil rhizosphere and many other microorganisms should also be considered (Hao et al., 2021).

5. *Considerations on transgenic plants*

Throughout history, many scientific phenomena have met with great scepticism and resistance in the early stages, but few pieces of knowledge have affected the basic structure of the universe as much as genetic engineering. Thus, the intrusion into the sensitive area and the very sensitive and effective laws of nature are accompanied by reactions, fear, and hope (Abbasishavazi et al., 2019). In addition, the presence of genetically modified oil could be predicted by consumers based on the planned behavior theory. In a research, the evidence showed strongest positive, significant correlations between Attitudes and subjective norms

(Abbasishavazi et al., 2019). In this context, many potential considerations for the development of genetic engineering were voiced in the early 1970s. However, the main problem with artificial GMO is the lack of enough information accessible in the public domain (Singh et al., 2022). However, transgenic plants offer a new production method for human antibodies and substances for treating anaemia and diabetes which has made plants as suitable bioreactor for the production of pharmaceutical components and many of them are targeted at a specific operation. (Ayan et al., 2022; Kowalczyk et al., 2022). Although it is sometimes claimed that GMOs have the negative consequences for biological diversity (Ghosh & Adhikari, 2022).

Tadich's researches show that to achieve better health, food security and sustainability, human needs to use biotechnologies with production systems (Tadich, 2022). Despite the consideration given to the potential dangers of these products, not only there is no scientific or documentary evidence of the harmful effects of these products on humans, but also reports suggest that the resulting food technology, like other common non-transgenic foods, can be healthy and unhealthy simultaneously (Ranjha et al., 2022).

Yali (2022) reported that Biotechnology can raise resistance ability of GMOs against disease and pests and enable the production of more nutritious staple plants for providing key micronutrients.

However, some researchers believe that the long-term effects of these products on human health have not been adequately studied; so further clinical trials studies in human populations are still needed (Shen et al., 2022). Furthermore, the researchers have not indicated how long the adequate long-term studies should last to ensure the health of these products. However, experts believe that the production of food is not without risk. Since a gene usually codes for a protein, new genetic information in an organism creates one or more new proteins. Foods produced from these genetically modified organisms contain new proteins that may induce sensitivity to some members of society (Shen et al., 2022). Recombinant genes introduced into the host plant are translated and expressed as proteins or enzymes. As a result of recombinant proteins or enzymes activity, secondary metabolites may be formed. Improving strategies for increasing the productivity of plant cultures in vitro must lead the design of highly efficient systems to the valuable secondary metabolites or recombinant proteins production (Kowalczyk, 2022). On the other hand, cellular metabolism of mechanisms used in food production may undergo unintended and unpredictable changes that may cause dysfunction, such as the inability to produce important vitamins in nutrients (Ortega et al., 2022). Notably, the consumption of non-transgenic foods can also cause mild or even severe allergies in people in a community. Thus, transgenic products are no different from non-transgenic ones (Yali, 2022; Carsono, 2022).

However, to avoid any possible and uncertain risk of consuming transgenic products, special measures and assessments have been proposed before these products are released on a commercial scale (Haga, 2022). Conducting these tests can significantly reduce the risk of consuming these products. The World Health Organization (WHO) emphasizes the health of transgenic plants by stating, "Transgenic foods may be beneficial if their safety has been evaluated." Thus, W.H.O confirms the benefits of transgenic foods for human health and the environment. To date, transgenic crops are grown on millions of acres of land and no health problems have been reported from human consumption of transgenic crops or their products. The introduction of any type of product resulting from genetic modification into the food chain requires adherence to safety measures to preserve human, animal, and biodiversity health. The United States, Europe, Japan, Canada, and other countries around the world have provided labelling and safety controls for transgenic foods to enter the market. To date, the European Union has laws controlling aspects from the release of transgenic plants to the final products of these plants (Kemsawasd, 2022).

As more than two decades have passed since the introduction of genetically modified crops (GM) into agriculture, technology experts and regulators have gained considerable experience in assessing their safety to humans, animals, and the environment. More than 3,500 independent regulatory agencies have assessed the safety of transgenic crops for food and feed. However, varying and extreme regulatory requirements have led to delays in approval and restrictions on access to innovative products for farmers and consumers. Safety assessments to date have led to a better understanding of the plant genome and safe use. Therefore, it is time to reconsider current approaches to the laws governing transgenic plants used for food.

Today, for example, consumer and market interest in meat and alternative dairy products such as plant milk, plant protein products, and cultured meat and milk is increasing. At the same time, statistics show no decline in meat consumption. A review of social science articles on cell- and plant-based meat and milk options indicates that the replacement of animal products with bioengineered products will influence their role in protein supply in the future. The existing literature review can be summarized in three contexts: 1) market pressures, 2) consumer preferences, attitudes, and policies to change behaviour, 3) government policies to support changing consumption patterns. More research is therefore required to understand the broad ethical implications of the food system for meat and dairy options. In addition, more attention needs to be paid to the impacts of meat and dairy substitutes at the farm level. Careful examination of these research gaps can help to better understand the potential for system change in the future (Lonkila & Kaljonen, 2021).

6. *The progress of biotechnology*

Bio-fortification of cereals has been practiced for thousands of years through natural and selective methods of species selection. In addition, modern farming methods today have changed the common selection techniques and later biotechnology. For example, these techniques can be used to increase the mineral (Zinc) and vitamin (vitamin A) content of cereals such as wheat and maize and other important root crops and legumes. Adapting maize varieties to different soil types provides methods to increase crop productivity and micronutrient content in specific locations and production systems (Obaid et al., 2022). Bio-fortification can also increase the nutrient content of feeds and hence livestock products such as eggs (Karel, 2021).

Hybrid seed technology is another attempt to produce improved seeds with higher yield characteristics than their parents over several generations of selective breeding. For example, the yield of corn in the United States doubled from the previous yield per hectare when this technology was applied in 2013. Also, about the impact of hybrid rice seed technology in China by Yuan Long-pin (father of hybrid seed technology); rice yield has increased from 2 million tons per hectare to 6 million tons per hectare (Desamero, 2007).

Another advanced method for the rapid production of plants is the culture of plant cells, tissues, and organs using special nutrients formulated under suitable conditions, and this has been going on for 30 years. In this method, the entire plant can be regenerated from a single cell (Széles et al., 2022).

Micro-propagation is a tissue culture method used in many plants to produce disease-free, high-quality plants and rapid production cycles. Growing many similar sister seedlings from actively dividing cells (meristems) requires a specific environment and plant hormones. As the meristem divides and multiplies faster than the virus causing the disease, a healthy plant is produced from it (ISAAA, 2020).

Embryo rescue involves assisting the germination of a plant-derived from parents with different genomes to find the desired characteristics of both plants in terms of their tolerance to environmental conditions. For example, a new type of rice plant was obtained from the extensive cross between the Asian rice *Oryza sativa* and the African rice *Oryza glaberrima*. In this method, the embryo rescue technique is performed on the first production of the embryo and then the consecutive crossing followed by the bulk production of the plant. The new plants obtain the combined yield characteristics of *Sativa* with the local adaptation of *Gaberrima* species (Wambugu et al., 2019).

GMOs: The current situation of these crops in the world from the beginning of commercialization in 1996 to the end of 2018 (Fig. 3), shows a 112-fold increase in the area under transgenic crops, from 1.7 to 191.7 million hectares (Baghbani-Arani et al., 2021).

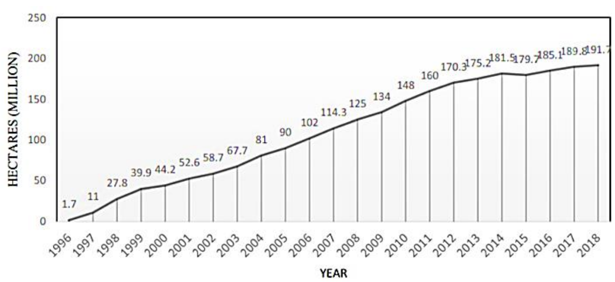

Fig. 3. Cultivated area of biotech products in the world from 1996 to 2018 (Baghbani-Arani et al., 2021).

Among biotech products in the world, soybeans account for the largest area under cultivation with 91.4 million hectares, which is about 50% of the total area used for transgenic crops (Ali et al., 2021).

GM products are currently grown by more than 60 countries and exported to more than 30 countries (Ali et al., 2021). Consuming GM plant foods can be just as dangerous as regular plant foods consumption. However, the foreign genes in these products may be unstable and lead to short-term nutritional and undesirable consequences. Due to lack of research, no long-term effects have been observed with the lifetime consumption of these products. But more research is needed to clarify the dangers and prove the lifelong effects on humans. So, the EU strategy is to expand organic farming via its new Farm to Fork (F2F) plan (Paarlberg, 2022).

Thus, the role of genetically modified crops in supporting sustainable food systems is controversial, and completely different definitions of sustainable agriculture underlie this debate. However, current unsustainable practices, including the use of pesticides in agriculture, endanger human health and ecosystems in the long term.

The history of using microorganisms to prepare foods such as vinegar, yogurt, cheese, and alcoholic beverages dates back more than 8,000 years ago. But today, in the science of genetic engineering (bimolecular or recombinant DNA), the techniques of isolating, purifying, inserting, and expressing a particular gene into a host to express a specific trait in an organism or to produce a product in a way other than natural methods are common. Selection and isolation of the desired gene, insertion of that gene into the vector, replication of the gene in the appropriate host, transfer of the gene carrier into the target cell, propagation of the target cell, and finally mass production of the product with a new trait are various steps used in genetic engineering. This is illustrated in Fig. 4 (Phillips, 2019).

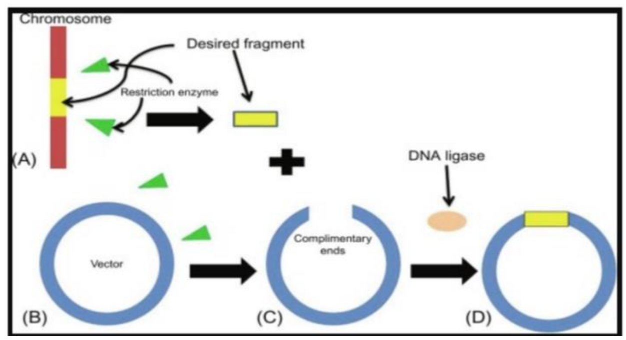

Fig. 4. Overview of the steps in genetic engineering (Phillips, 2019).

Soybean as the most transgenic crop in the world currently with genetic modifications addresses the ethical and public acceptance issues (Rahman et al., 2022), widely used in various fields such as animal and human use. It is also part of the formulation of meat products that are easy to be eaten and are usually consumed without the need for cooking, which is not easy with meat, and provides consumers with different tastes the necessary amount of proteins that contain essential amino acids. Transgenic products indeed have definite benefits, but their biosafety is also a concern. Although no adverse effects have been reported to date, thorough and accurate evaluation of such products before release, as well as consumer information and choice about the transgenicity of the product, is essential (Yakovleva & Kamionskaya, 2022).

Gene Editing: the latest version of genetic engineering that relies on species-specific nucleases (SSNs) to insert, delete, or modify specific genes. CRISPR-Cas9[1] is the latest advanced method and is more effective and economical than previous methods (Pal, 2022), which is much more useful for altering multiple genes in a plant. Gene modification methods have already been successfully tested on major crops such as barley, corn, rice, soybeans, sweet oranges, wheat, and tomatoes. In addition, there are now many traits for herbicide resistance, salt resistance, drought tolerance, nutrient content improvement, and resistance to biotic stresses that are currently being researched. The CRISPR-Cas9 technique is more accurate and predictable than previous technologies (Pal, 2022).

[1] The CRISPR/Cas9 system commonly used for genome editing involves the cleavage of DNA by the RNA-guided DNA endonuclease Cas9.

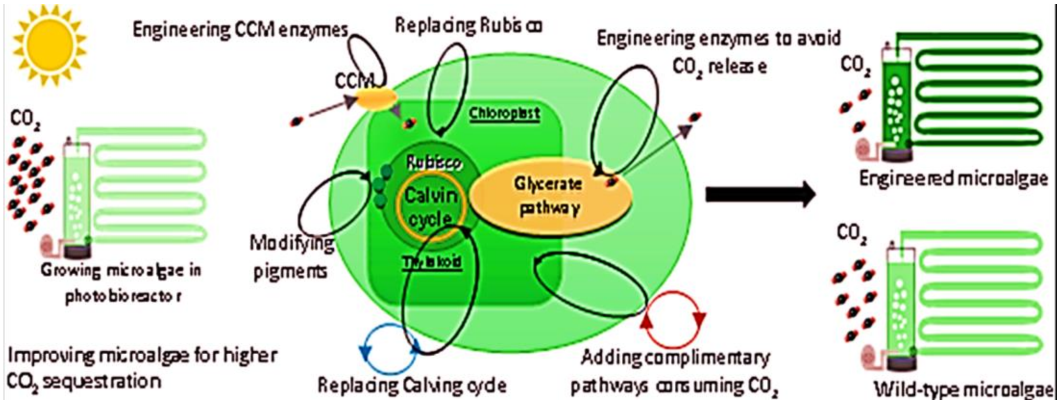

Fig. 5. Illustrative summary of genetic modification of microalgae with the approach of increasing the uptake of carbon dioxide from the atmosphere and altering weather conditions (Barati et al., 2021).

However, this question arises, whether the new techniques of GM, known as gene editing, are useful for sustainable agriculture?

Because of the issues of golden rice, the fundamental question is whether gene-editing techniques are more accurate and their results more predictable? Do these techniques meet the needs of agriculture or, more broadly, the social and environmental needs of sustainable agriculture? (Long et al., 2022).

7. *Environmentally friendly approach*

Reducing carbon dioxide (CO_2) emissions into the atmosphere has been a hot research topic in recent years. Cultivation of microalgae using CO_2 from power plants and factories has been introduced as an environmentally friendly approach. However, to achieve a stable integrated system, algal strains with high biomass efficiency are required. Improving photosynthetic conditions to increase biomass productivity and reciprocally increase CO_2 uptake from the existing air composition is too important. The improvement of photosynthesis can often be achieved by increasing the efficiency of enzymes involved in CO_2 fixation. These changes can be achieved by modifying and editing the algal gene. The gene structure of microalgae modification, therefore, has been discussed as a very challenging task in the last decade. In recent studies, digestion of the cell wall of microalgae has been introduced as one of the main obstacles to gene modification. Moreover, ribonucleoproteins composed of Cas9 in algae (Cas9 protein gRNA), which do not require vectors, have been proposed as an efficient method for gene editing (Barati et al., 2021). Fig. 5 shows a visual summary of the recent article.

8. *Genetic engineering through direct gene editing*

CRISPR-Cas technology as the new harmless face of genome editing with its wide range of applications is rapidly spreading in both academic research (reverse genetics and functional genomics) and applied research to create new types of products with improved properties. For example, the United States is revising its existing regulations for CRISPR-modified organisms. At the same time, the European Union is classifying all types of CRISPR-modified products as genetically modified under the new regulations, which are process-oriented, and categorizing SDN1, SDN2, and SDN3 (site-directed nuclease) results as GMOs (Ogwu, 2021). These products have enormous potential for global agriculture and food security. To meet the global challenges of food security and sustainable agriculture, a scalable monitoring system based on newly modified genomic products is needed (Ogwu, 2021).

Crops through genetic engineering CRISPR-Cas gain exceptional ability to combat plant stress and non-living factors caused by climate change, environmental resilience, and food security. Since the discovery of CRISPR-Cas technology, it has largely proven to be useful. Despite the revolutionary nature of genome editing tools and the significant advances they have made in plant genetics, there are still many challenges for CRISPR applications in plant biotechnology. By improving gene editing efficiency in the germination pathway, nanomaterials can help plants overcome some of their challenges. The CRISPR vision removes key barriers that prevent plant genetic engineering from reaching its full potential, facilitates and accelerates genome editing in plants, and improves our ability to feed a growing human population in the face of changing global conditions (Tailor et al., 2022).

9. *Biosafety regulations of Iran and the world*

CRISPR-Cas Iran is a major importer of agricultural products, especially soybeans. In the first six months of 2021, the largest imports of agricultural and food products, which accounted for 86% of Iran's total imports, came from Turkey ($692.2 million), India ($595.4 million), the United Arab Emirates (553.3 million), and the United Kingdom ($447.2 million), the Russian Federation ($430.7 million), the Netherlands ($268.1 million), Germany ($185.3 million), Brazil ($114.8 million), Singapore ($111.4 million), Pakistan ($85.1 million), and Switzerland ($69.8 million) (Ogwu, 2021).

China, Brazil, and especially Argentina are Iran's main suppliers of transgenic soybeans. Since transgenic soybeans are used in the production of meat products such as burgers, sausages, and hot dogs, Iran needs to enact a law on the health evaluation and labeling of biotechnology products (Ogwu, 2021).

Many international organizations have addressed the challenging issue of consuming GM products by establishing some principles, standards, and guidelines to increase safety and reduce concerns about these products. The Cartagena Protocol on

Biosafety can be considered the most important binding international standard. 158 countries (such as Iran) now adhere to this protocol (Tailor et al., 2022).

The Cartagena Protocol on the Food Codex of Diversity and Biosafety is linked to the Convention on Biological Diversity (CBD), which regulates the management of GMOs. One of the general objectives of the Food Codex is to collect and adopt international food standards and present them in a uniform form. It was created in 1963 during the 16th session of the World Health Organization (WHO) to implement common FAO/WHO food standards (Baghbani-Arani et al., 2021). To date, more than 172 countries have joined this commission. Iran is one of the countries that are members of this commission, whose first statute was published in 1998. In 2001, Iran signed the Cartagena Protocol on Biosafety and was obliged to implement the law on biosafety of genetically modified plants and the resulting microstructures. The Ministry of Agriculture Jihad, the Environmental Protection Organization, and the Ministry of Health, Treatment, and Medical Education are responsible for the implementation of this law in Iran. One of the objectives of this Act is to safely expand the applications of molecular biotechnology to maintain and improve the health of society and to develop a framework for monitoring the importation and labelling of raw and processed imported products derived from genetically modified organisms or their contents. According to the guidelines issued by the Ministry of Health and Medical Education for the import of genetically modified products, the mentioned food products must be labelled as it is a natural right of the consumer to know whether they are organic or transgenic products in the food basket used.

In 2019, Iran's Ministry of Health and Medical Education declared only three transgenic crops, including oilseeds from rapeseed, soybean, and corn, as approved products, meaning that all soybeans imported into Iran are genetically modified. This means that people in Iran have been consuming transgenic crops for more than 15 years. On the other hand, more than 6 million tons of corn (used for imported livestock and poultry feed) and cottonseed (used for oil production in the Iranian market) are transgenic (Ali et al., 2021).

European regulatory documents for the release of transgenic plants and the status of plant-modified plants are listed in Table 2.

Transgenic have been grown in 28 countries for more than two decades. However, there are still uncertainties regarding environmental and safety issues; while, due to the many benefits of genetically engineered products, it is predicted that they will dominate the future and replace other similar products (Poole et al., 2021).

10. Conclusion

Biotechnology, through genetic modification, can play an incredible role in reducing the vulnerability of natural and human systems to the effects of climate change, including greenhouse gasses, and increasing agricultural production on less land by contributing to future food supplies through transgenic traits such as herbicide resistance, drought tolerance, and insect resistance; high-yielding transgenic crops produce and mitigate the negative effects of climate change. Biosafety monitoring systems created with development policies and the use of sustainable agricultural biotechnology involving public and private organizations must effectively use modern biotechnology to increase food security and reduce climate change.

Modern biotechnology is currently the subject of much public debate on the risks and benefits of GMOs in terms of human health, the environment, socio-economic aspects, and ethical and cultural issues. However, the safe use of modern agricultural biotechnologies contributes significantly to moderating and mitigating the effects of current and future climate change. To ensure that food is available to all and that food resources are used efficiently worldwide, it also significantly improves agricultural productivity and food security, and ensures that transgenic crops do not harm living organisms and the environment. Agricultural productivity must be doubled or multiplied to feed the growing world population. So, future work can be focused on the genetic modification for ensuring food safety and security. Therefore, under the international law, countries must implement quantitative and qualitative analysis methods in international laboratories for using in labeling systems and also address emerging food security challenges; risk and benefit analysis is essential. Because instead of leaving the subject and paying too much attention to the moral debate; It is essential to pay attention to quality scientific information.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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