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Genetically Modified Foods: Promises, Challenges and Safety Assessments

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Abstract

Background and Objective: Application of genetically modified organisms in the agriculture sector and food industry began since last years of 20th century. Since then this technology has become a central part of the broader public controversy about the advantages and safety of these products. This article has tried to review aspects of these types of organisms and foods.

Results and Conclusion: Genetically modified technology has potential to overcome agricultural problems, such as biotic and abiotic issues by enhancing pests and herbicides resistance, drought tolerance, fast ripening, and finally enhancing yield and nutritional quality. Besides these revolutionary advantages, during the last decades some potential human, animal and environmental risks have been taken in account for these organisms or foods. However, no scientific evidence exists adequately about their harmful human or animal effects, and also, some new scientific and management methodologies (new technologies and regulations) have been developed to mitigate the environmental risks. Some challenges such as pest adaptation are being solved by refuge technology, gene pyramiding and insertion of best-coupled primers through the known conditions reducing unintended outcomes including silencing, activation or rearrangement of non-target genome pieces. However, it does not mean that no harmful effect will happen in the future. Therefore, it is required that before release of any genetically modified crop, all requested risk assessments be performed, and then post release monitoring be done to follow the possible gene flow and prevent any potential disastrous contaminations to the food chain. Finally, it could be concluded that the safe usage of this technology, by considering all nationally and internationally accepted environmental and health safety assessment protocols, can help us to use advantages of this technology in agriculture, medicine and industry. However, more safety evaluations are being done frequently.

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1. Introduction

According to the definition of World Health Organization (WHO), genetically modified organisms (GMOs) include plants and animals which are modified genetically rather than conventional breeding approaches. So, a GMO is an organism whose genome has been altered by the techniques of genetic engineering at in vitro level so that its DNA contains one or more genes or other gene expression elements not normally found there. In 1994, the US Food and Drug Administration (FDA) has approved the first genetically modified (GM) tomato (Flavr Savr) containing delayed ripening characteristics [1]. After that various GM varieties of different plant species have been approved to be released in the environment or to be used as food, feed or for processing. For instance, several GM varieties of canola, cotton, soybean, potato, eggplant, strawberry and carrot have been approved by FDA during recent years [2]. The first generation of GM crops has been developed for yield and quality improvement by inducing pests, disease, drought and herbicides resistance, and salinity and cold tolerance. However, the second generation of GM crops is in pipeline for improvement of nutritional quality and also production of recombinant pharmaceutical proteins (molecular farming) [3]. Recently, DNA sequences have been extracted from soil bacteria and plant pathogenic bacteria and viruses. Their insertion occurs by one of the two principal methods, which are Agrobacterium-mediated transformation and micro-projectile bombardment [4]. Crops have been drastically changed by genetic engineering; nonetheless, gene performance can be affected simultaneously by the environment and in-farm practices. Environmental factors are as effective as intrinsic parameters. It was shown that heat was more important than genetic modification in expression of anti-nutrients in crops including maize,

potato, tomato, and soybean. For example, *Arabidopsis* disease resistance is attributed to DNA methylation. It was found that environmental factors affecting methylation process or chromatin conformation would induce gene silencing and different results would be seen. So, their final performance would also be pertained to geographic location and method of cultivation [5,6]. Besides revolutionary advantages of GM crops during last decades, some potential human, animal, and environmental risks have been taken in account for GM organisms or foods. A large number of experiments and data are needed to enable scientists to determine the safety of GM corps and their likely health concerns [7]. Therefore, the aim of this review article is to gather previous findings, current evidence, types of assessment, and legislations associated with genetically modified products to alleviate ambiguities arising from this technology.

Potential promises associated with GM foods

Current world population is more than 7 billion [1] and it is anticipated that it will raise to 9.3 billion in 2050 [8]. According to FAO, 795 million people suffered from malnutrition in the world in 2015 [9]. Increasing world population and feeding demands should be correlated with increasing yield to comply the overall demands. Paucity of food (food insecurity), water and arable lands have forced governments to develop genetic engineering technology. Genetic engineering has been taken in account as one of important technologies which can have a key role in overcoming such problems in the agriculture sector. Countries with high population such as China and with dense population and narrow arable land, such as Japan, have extensively invested in GM crops. In 2015, 3.7 million hectares were planted with GM crops in China. Chinese governments have paid more than 3 billion dollars on GM research for domestic GM seed development paralleled to their testing and approval [10]. To date, GM crops are planted widely worldwide. In 2016, 185.1 million hectares (equal to 457.4 million acres) were cultivated by 18 million farmers in 26 countries. This statistic shows an increase of 3% or 5.4 million hectares (13.1 million acres) compared to 2015 [11]. It was investigated that planting of GM crops reduced about 27 million tons of CO_2 emission in 2014 [12]. Aggregation of benefits including low cost, improvement of nutrients in the same crops and the most important lowering mortality and malnutrition has made GM technology popular in some societies [13].

Development of crops characterized with delayed ripening, resistance to insecticide, herbicide, drought, black spot, viral disease, and fusarium infection are other positive outcomes of GM technology [1,14]. In some cases, the purpose of genetic engineering is bio-fortification by health promoting agents such as vitamins, fatty acids, and minerals especially in staple crops. Indeed, the first generation is aimed at increasing yield and the second generation is designed for quality improvement [15]. Regarding the latest traits, it would be applicable to use transgenic crops as oral vaccines to stimulate the immune system in producing antibodies. Some crops including rice, maize, soybeans and potatoes are understudying against *Escherichia coli*, rabies virus, *Helicobacter pylori* and type B viral hepatitis [1]. Genetic engineering can produce hypoallergenic soybean or altered qualified analogues with the same allergenicity [16].

Another example is GM maize expressing crystal (cry) proteins from *Bacillus thuringiensis* (Bt) to diminish insect damage and fumonisin infection in comparison to non-GM counterparts [17]. Using Bt toxins is considered as the most widely applied approach since the evolution of GM crops [18]. It has been approved by WHO and Environmental Protection Agency (EPA) and has no safety concerns for humans owing to its specificity to target organisms [19,20]. Cultivation of Bt crops decreased the amount of chemical insecticide in South Africa over 20 years [21]. The mechanism is that the cry proteins attack to the mid-gut of insects and make lesions or wounds in host epithelial cell membrane which results in septicemia. In contrast, it is safe for humans because there is no equivalent receptor in human gut for cry protein [22,23]. Besides horticultural effect, it is environment friendly due to lowering chemical insecticide consumption [17].

Soil organisms are firstly exposed to Bt toxins after crop death. They have the drastic roles such as nitrogen fixation, growth promotion, and nutrient solubilization. Therefore, the effect of cry protein should be investigated in risk assessment. It has been revealed that there is negligible or no concern about its harmful effect on soil ecosystem. No adverse effect on soils vital organisms such as mites, collembola, and earthworm was shown in experiments and field studies [23]. One exception is lowered growth in exposed snails to Bt maize [24].

A large number of Bt cottons is cultivated in Pakistan in recent years with yield increment by 28% and pesticide cost reduction by 17% over non-Bt varieties. Reduced pesticide use has produced health and environmental benefits of 79$ per acre [25]. Increased yield has also generated substantial female employment effects in the country [26]. Nevertheless, Bt cotton adoption in India has reduced pesticide use more than 50% during 6 years [27]. No adverse histo-pathological changes were observed in the study of rabbits' liver and kidney, which were treated by seeds and leaves of Bt (alteration in Cry1Ac Mon 531 gene) and non-Bt cottons during 90 days. They also did not show any significant differences in weight gain. It was found that Bt gene did not cause detrimental changes to the DNA integrity [28]. One other achievement in Bt maize

technology was control of fusarium infection. Mycological analysis based on ergosterol measurement (as specific component of fungal membrane) [29] revealed that ergosterol level in Bt maize was 4-18 times lower than control hybrids [30]. Some other characteristics could be transferred to cotton; for example, luster, softness, good elasticity and warmth retention property were induced in engineered cotton varieties by importing animal keratin genes [10].

Regarding Bt corn, another study verified no allergenicity over 30 years of commercial use and no occupational allergenicity through its modification was observed. In comparison to the control and GM counterparts, no meaningful compositional, phenotype and micronutrient level was found [4].

Other than Bt crops, genetically engineered rice (Xa21) was also evaluated. Like other GM foods, no detrimental, toxic and allergenicity consequences were reported for GM rice. In practice, 3 fold up expression of pullulanase was measured in proteomics studies over the control. Pullulanase is responsible for the alteration of starch structure in rice endosperm by its enzymatic (de-branching) activity [31]. Further, higher expression of glutamic acid (23.40% vs. 19.38%) observed in GM rice which was interestingly within the reference range reported previously [32].

Herbicide tolerance (such as phosphinothricin tolerance) is another approach in genetic engineering. Crops containing the gene encoding Phosphinothricin-N-acetyltransferase (with no known toxic effect) extracted from aerobic soil actinomycete and *Streptomyces hygroscopicus*, tolerate glufosinate (an active ingredient in herbicide which is resemble with amino acid glutamic). Glufosinate interferes in enzyme glutamine synthase activity and lead to lower glutamine level and ammonium accumulation in plants. This results in plant withering and death by disruption of cell membrane and cease of photosynthesis. Herbs resistant to glufosinate by enzyme degrading phosphinothricin and changing it to inactive compound can grow in the farms sprayed with herbicides [33].

Potential challenges associated with GM foods

Despite the advantages of GM crops mentioned above, some scientists raised environmental and health concerns about these products and believe that GM technology has failed in recent decades. They worry about its serious threats to the biodiversity, evolution of resistant pests, and side effects impacting humans and animals as well as the environment [34]. For instance, there was a demand on GM free wheat by the buyers in 2013 when the unexpected glyphosate resistant wheat was found in Oregon farms and made a threat for the U.S. trade with GM opt-out countries including Japan, South Korea and European Union [14]. In contrast, situation is different in America. The U.S is the most investor and producer of GM foods and half of global GM crops are cultivated there through science-based institutions assisted with risk assessment approaches. Thus, it is obvious that American governors and traders have less rigorous regulations on GM compared to European countries. While Canada is the biggest canola producer, Mexico is not against GM crops as much as Europe but it is reluctant to approve GMOs beyond pilot trials [13]. Almost 90% of GMOs are taken by consumers through GM derivatives made in industry and just about 10% are consumed directly [35]. The Cartagena Protocol on Biosafety is the most important obligatory regulation on safe trade of living modified organisms. By 2017, about 171 countries are as members of this protocol. One of the most important principles in the CPB is risk assessment and consequently risk management [36].

As a rule, risk assessment should consider all aspects of DNA recombination so that the final product and also the method of cultivation have not had unexpected adverse effects on both human and the ecosystem. Based on the CPB protocol, risk assessment should be performed in a scientific manner and case by case. Clinical adverse effects are pertained to disruption, activation or silencing of existent genes or any other changes such as rearrangement [4,32]. Concerning the ecosystem, it is necessary to investigate the possible effects on water, soil, air and animals owing to potential harms associated with GM release into the environment. Main human safety concerns are related to their toxicity, allergenicity, and other possible hazards arising from inserted genes, expressed proteins, potential pleiotropic effects due to metabolites other than the target protein, and non-target change in gene integrity due to its manipulation. In biosafety, there is a difference between animals and plants. In general, animals having a safe history of use in dietary patterns do not have genes encoding for harmful metabolites. But, the situation is different in plants. There are some plants which are safe for use but contain toxic agents that require detoxification before consumption. Some examples are ricin in castor bean, trypsin inhibitors in soybean, etc. This issue is not restricted to gene engineering and affects conventional breeding as well [37].

Unintended outcomes must be assessed in general. They might not be deleterious necessarily and might pose beneficial or neutral role in plants or foods derived from them [4]. In risk assessment approaches, it is important to find out that if the novel protein would induce a secondary effect on plant or human. On the other hand, expression of proteins as intended target may result in the accumulation of secondary metabolites [37] or the modification may mediate new enzyme production involved in other metabolic pathways and participates in new metabolite

production [1]. Therefore, the role and activity of secondary products should be investigated critically.

One challenge is to set a qualified method in the analysis of new traits. For example, engineered rice for reduction of glutelin level was associated with the increase of prolamin. Both of them are a type of gluten protein and are responsible for allergenicity in coeliac disease. It was found that new change could not be detected by standard nutritional analysis including total protein and amino acid profile and the difference was detected just by sodium dodecyl sulphate-polyacrylamide gel electrophoresis. Differences like this would not influence the industrial application, but nutritional quality and further allergenicity would change especially when it occurs in staple foods such as rice. Same results were observed in production of Golden Rice. Aim of this design was production of high level of beta-carotene in rice as precursor of vitamin A. This change was unexpectedly accompanied by higher production of xanthophylls, so that it could not be detected by standard nutritional analysis and high pressure liquid chromatography was used alternatively [4].

Some other drawbacks are also addressed to GM technology. Insertion of resistance gene into crops had led to the resistance of target pests. A known example in recent years is evolution of resistant insects to Bt crops containing gene encoding cry proteins. Although, this phenomenon was solved temporarily by a strategy named "refuge" including cultivation of non-Bt crops near the Bt counterparts. Refuge limits and delays the domination of resistant pests significantly [17]. There are several parameters that should be considered for controlling this process. Resistance severity depends on type of pests. Propagation of resistance would occur by mating of resistant and susceptible pests in farms. Then, if the hybrid gene is not recessive, the new trait would evolve. Moreover, the ratio of refuge and transgene is determinative. On the other hand, dominance of resistance and refuge abundance are in a counter relation to each other. Using higher percentage of refuge would prolong the period of resistance evolution. For example, in the case of *Helicoverpa zea*, using 70% refuge compared to 30% transgene required more than 20 years for resistance evolution [38]. Another strategy is gene pyramiding in which many Bt genes are transferred to the genome of crops to delay pest resistance. In this way, insects are faced with multiple toxins [39]. Nonetheless, increased yield is a promise of GM technology that cannot be neglected. Consideration of all effective parameters is a proper alternative to combat the mentioned drawbacks.

Horizontal gene transfer is a process in which DNA would transfer between organisms (plants, animals and microorganisms) interchangeably. There is a concern in gene exchange and contradictive opinions are reported. Some studies report that gene interchange occurs rarely, while other studies declare that transgenes could be taken by the environment or consumers' digestive bacteria. There is a claim that the acidic environment in digestive tract and thermal process would degrade ingested foreign genome by transgenic foods [40]. Although, adverse statements are based on hypothesis and no proven evident has been introduced but the possibility should not be completely discounted and considering widespread usage and abundant diversity of transgenes in the world may make it possible in the near future [34]. It is worth saying that gene transfer from one organism to another is a complex process and needs consecutive stepwise events [7].

One controversial issue in GM technology is the insertion of antibiotic resistance genes as natural markers. This approach is to insure scientists that the target gene has been inserted into the cells. In practical, plants containing new genes would be resistant to antibiotic while other counterparts cannot grow. For example, two plasmids containing bla gene were used in soybean transformation. The bla gene is responsible for the expression of lactamase enzyme which degrades lactam antibiotics such as penicillin and ampicillin [4]. Although, it is accepted as a safe pathway because of their widespread persistence and rare possibility of transfer [41], but some GM critics worry about transfer and expression of antibiotic resistant genes to inhabitant bacteria in gastrointestinal tract. It should be noted that transfer process would occur by stepwise events that make it unlikely.

The process is as below:

- Excision of gene encoding antibiotic resistance together with bacterial promoter
- Survivability of that gene in gastrointestinal tract
- Transfer of survived gene into bacteria in gastrointestinal tract
- Compatibility of target gene with bacterial system towards joining host genome
- Stable integration of target gene containing antibiotic resistance trait into host genome
- Keeping integrity and further expression in host bacteria

Other than the complexity of process, there is a fact that bacteria present in digestive tract are already resistant to ampicillin. Therefore, even by neglecting the low possibility of bla gene transfer to digestive tract bacteria, there would not be any health concerns about bacterial resistance to lactam antibiotics such as ampicillin which is rarely advised clinically in recent years [4]. Environmental disasters including pollution derived from the longtime use of herbicides and biodiversity reduction are some difficulties associated with this technology [22]. Studies stated that use of herbicides and pesticides would increase after evolution of GM resistant plants. Acclimation of

weeds and insects to in-farms chemicals forced farmers to use more amounts of chemicals or use other more efficient alternatives which might have more adverse effects on human, animals and the environment. Comparative studies show that the use of glyphosate have been increased with a sharp trend since 2005 [42].

Glyphosate used for GM plant protection would ultimately release into the soil and stimulate the growth of fungus, Fusarium. The fungus can induce botanical infection [43]. Fusaria have a potentiality of toxin production, which have carcinogenic and cytotoxic effects [44]. The International Agency for Research on Cancer (IARC) has classified glyphosate in group 2A. It means that it is "probably carcinogen for human". Although, the European Food Safety Authority (EFSA) believes that glyphosate does not cause carcinogenicity if used within the range of maximum residue limits [45]. It has been proved that glyphosate affects soil's living organisms differently depending on dosage, number of applications and biochemical conditions of soil. For example, soil's pH has a discriminative role so that microbial growth would be inhibited strongly in neutral soils than acidic or alkaline media or in soils with the lower levels of organic carbon. Following microbial degradation, the pHs out of neutral point induce mineralization and binding of phosphor moiety to soils' reactive components such as minerals. Therefore, the lowered toxic sequence on plant and soil microbes is expected because of the unlikely degradation by quenched metabolites as a result of their lower potential of penetration to cell membranes. Also, lower organic carbon causes the lower buffering strength, which makes plants more sensitive to stress factors [46].

In general, it is important to distinguish between hypothesis and proved health problems. Although, the higher use of chemicals in response to the acquired resistance of pests due to continued consumption of chemicals is reported, more expanded investigations by focusing on risk assessment of human and the ecosystem are required. A breadth of expertise in agriculture, veterinary medicine, microbiology, food technology, and immunology should collaborate to produce comprehensive safety guidelines concerning the GM products [1]. Furthermore, ethical issues should be considered by the governments. Mentioning GM source on food labeling gives a choice to consumer in selection of food items. Number of unintended metabolites can be reduced by exact deposition of promoter and terminator sequences in the way that confirm the right transcription of target gene and expression of intended protein [47].

General safety evaluation

Food safety issues of GM crops were investigated comprehensively by Codex Alimentarius Commission. These issues had been more focused by emergence of food labeling guidelines for consumer awareness [7]. Since then, this technology has become a central part of broader public controversy about safety on prolonged consumption of these food products. There has been a severe concern that GM products may act adversely as toxins, anti-nutrients, and allergens [32]. Therefore, more safety evaluations should be done, for instance, toxicological studies by animal model system at least during 90 days in sub-chronic trials, and through long term cohort studies in societies [10,48]. However, no adverse safety effects on human have been currently reported for more than 20 years consumption of GM foods in the World [35]. Scientists are seeking the minimum copy and size of DNA inserted in host plants to facilitate risk assessments and consequently the regulatory trends. It is pointed out that multiple insertions would not result in lower safety necessarily. However, various transformations may occur due to random insertion. Furthermore, phenotype-based approach in small scale cultivation as an initial screening can remove undesirable traits or events before vast cultivation. If crops can pass through this stage, which is done by breeders, they would undergo the safety assessment [4].

Unintended effects are subdivided into "predictable" and "unpredictable" [49] and could be analyzed by genomic strategies with the aid of bioinformatics tools [50]. In a comparative approach, three factors are considered: a) molecular characterization, b) phenotypic characterization, and c) compositional analysis [37]. New proteins are expressed as low as 0.1 percent of plant tissue per dry weight. While, in biosafety studies, large amounts of protein expression are required. So, bacterial expressed proteins are purified and used instead. In such studies, functional equivalence including physiochemical properties and biological activities of both sources of proteins are needed [4].

Risk assessment

Risk assessment is a helpful approach in monitoring hazards arising from foods. The approach consists of hazard identification and characterization by toxicological studies, exposure assessment through epidemiological studies and risk characterization by considering achieved data. Diminishing variability and uncertainty in risk assessment is important for further process [51]. Risk assessment of GM crops has been conducted during more than two decades worldwide by considering three aspects: 1) physiology of crops affecting evolution of specific hazards (e.g. trypsin inhibitors in soybean, solanine in potato, erucic acid in canola oil etc.), 2) dietary exposure which relates to sequence of consumption by human, 3) possibility of health concern regarding characterized hazards [52]. In detail, risk assessment in GM foods consists of molecular characterization of gene sequencing, similarity tests compared with counterpart allergens or

toxins, protein toxicity tests, quantitative studies of new traits or metabolites, nutritional equivalence studies, animal studies, and also dietary exposure [47]. In this process, a safe history of conventional counterpart is used as baseline and a relative safety of modern crop to conventional samples with a long history of safe use is monitored or evaluated [53]. Correspondingly, the GM food is expected to be as safe as its conventional analogue under controlled processing and consumption. It means that GM crops must be substantially equivalent to conventional crops except in their new added traits [4]. Although critical hazards and risks must not be neglected, emerging GM technology by various promising expectations should be evaluated as a whole and further decisions should be taken based on the risk-benefit comparisons in risk management step [48]. This justification arises from the fact that natural crops may have some adverse components such as solanine in potato or allergenic proteins in soybean. The joint Food and Agriculture Organization (FAO)/World Health Organization (WHO) expert consultation has declared that safety assessment needs stepwise approaches; in comparison, substantial equivalent is different from safety assessment as it does not identify and characterize hazards but should be used for identifying safety assessment of conventional crops compared with recombinant counterparts [4]. In risk management step, based on obtained information, analyzed results and current policies, the level of acceptable risk would be determined by managers and they decide to accept or reduce existent risks [54]. This is the fact that prefers food security to food safety in societies. The Biosafety Clearing-House constructed by the Cartagena Protocol on Biosafety is to exacerbate sharing information about living modified organisms and help members to comply their commitments by using released protocol. Essential information including characteristics of promoters, terminators and gene encoded are illustrated for each product. Roots of risk assessments based decisions on registered GMOs are accessible [55].

Assessing the safety of newly expressed protein has a general procedure as elaborated below:

Depending on the source of expressed protein in target crops, two assessment procedures are used. When the source is allergenic, both sequence homology and potential allergenicity of protein by serology tests would be conducted [56]. In practice, when sequence homology to a known allergen is proved, the GM crop is classified as allergen and no further studies are needed. One example is GM soybean enriched with methionine which is allergen to sensitive individuals [2]. Similarly, gene encoding the amino acid extracted from Brazil nuts is also allergen. In contrast, when no sequence homology to a known allergen is shown, serological test for expressed proteins is done by serum samples containing high levels of IgE specified to gene source [57]. When serological test is positive, the protein would be allergen. In comparison, when a negative result is achieved, gastric digestion by pepsin resistance test and also animal study on immunogenicity of expressed protein are undertaken. In the next step, additional safety assurance can be provided once GM product is released in the market. This survey is recommended because of the wide genetic diversity in populations and different dietary patterns depending on geographical residence [58]. Finally, determination of proximate composition is favorable [4]. If composition of engineered crops changes, further investigation is recommended to assess the changes of nutritional status and bioavailability of components in daily intake [37].

Additional issues should be focused when viable organisms are present in final product such as fermented foods. Significant issues include antibiotic resistance and possibility of their gene transfer, pathogenicity, immunological effects, and viability in digestive tract [37]. Genes encoding antibiotic resistance are used as selectable marker. But, it is emphasized that these markers should not be inserted in live microorganisms which are present in foods. Otherwise, it should be approved that food components derived from such microorganism are free from viable cells [37].

International regulatory bodies: Overall view

Using GM products are doubtful because of contradictory views. In the one hand, it is verified by some scientists and organizations with no adverse effect while some other departments decline their usage due to further possible consequences. Although no distinct law rules out their processing and market release, it does not mean that no harmful consequence would occur in the future. It should be kept in mind that all potential hazards and risks must be considered in advance. Overall caution is a fact that is implemented by the European Union by conducting a risk assessment and management protocol. European Union is concerned regarding GMOs processing and demands a robust management [10]. American governors and investors are enthusiastic about GM food trade and regulations. In 2015, Barak Obama directed three federal agencies responsible for biotechnology -Environmental Protection Agency, Food and Drug Administration, and Department of Agriculture- to upgrade current regulations, conduct a prolonged strategy for the future of biotechnology, and commission expert committee for investigation of future overview of biotechnology products to support former efforts [59].

However, international agencies are responsible for their international acceptance, standardization, and advice. The Cartagena Protocol on Biosafety is the main resource

associated with living modified organisms derived from modern biotechnology. In 2000, Cartagena Protocol on Biosafety was adopted by Convention on Biological Diversity parties in order to protect biological diversity from potential risks arising from living modified organisms derived from modern biotechnology. It provides necessary information for countries in making decision for import of GM products. Biosafety Clearing-House is established by Cartagena Protocol on Biosafety to assist countries in sharing information [36]. Other bodies are Organization for Economic Cooperation and Development (OECD), WHO, FAO, EFSA, and Codex Alimentarius Commission [60,61]. More than 20 stacked GM crops were evaluated by European Food Safety Authority as a robust administration in risk assessment. The results have shown no adverse consequences associated with the interaction of single traits with regard to compositional, agronomic and phenotypic alterations [62].

In 1988, the United States National Research Council (US NRC) concluded that the final GM products should be a base for making decision on potential environmental hazards and risks of GMOs, not the process by which the product is achieved. They also believe that the process is applicable in finding out the products characteristics [63]. According to this report, field trials should consider three scopes:

- Acquaintance: a general knowledge about traits, events, and their possible effects on the environment.
- Control action: in some cases, there should be the ability of confinement or control of GMOs spread, if necessary.
- Risk estimation: for evaluation of further harmful consequences if the crop would be out of control or confinement.

2. Conclusion

GM crops are widely produced and used worldwide and their benefits are not negligible. Considering all concerns and doubts related to GM technology, international agencies have accepted usage of some products prepared by specific genetic occurrences based on in vitro and in vivo trials. Beside potential promises and challenges mentioned in the current review, it should be noted that today there is a severe crisis of water paucity and reduced rainfall in a vast geographical regions. Also, shortage of food supply in some countries and malnutrition in others draw the attention to the food security challenges. Making new changes in genome transcription toward production of high yielded crops with favorable metabolites such as higher amounts of oleic acid in vegetable oils, and crops fortified with some vitamins and minerals are some examples of promising roles of this technology in eradication of famine and malnutrition. However, more safety assessment studies of GM technology are required to evaluate the possibility of any unintended effects in the future.

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4. Conflict of interest

The authors declare that there is no conflict of interests to be declared.

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فراورده‌های غذایی تراریخته: پیامدهای مفید، چالش‌ها، و ارزیابی خطر

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چکیده

سابقه و هدف: کاربرد سازواره‌های تراریخته در حوزه کشاورزی و صنعت غذا به سالهای پایانی قرن ۲۰ میلادی برمی‌گردد. از آن زمان به بعد فواید و سلامت محصولات به دست آمده از این فناوری یک موضوع بحث برانگیز در مجامع عمومی شده است. در این مقاله تلاش شده است تا جنبه‌های مختلف این نوع سازواره‌ها و غذاها مورد بررسی قرار گیرد.

یافته‌ها و نتیجه‌گیری: فناوری اصلاح ژنتیک توانایی بالقوه‌ای در مقابله با مشکلات کشاورزی شامل موضوعات حیاتی و غیرحیاتی دارد که این مهم از طریق افزایش مقاومت به آفات و علف کش‌ها، تحمل خشکسالی، رسیدن سریع، و در نهایت افزایش بازده و کیفیت تغذیه‌ای دست یافتنی است. در کنار این فواید مهم، در طول دهه‌های اخیر تعدادی از خطرات بالقوه انسانی، جانوری و زیست محیطی برای این سازواره‌ها یا غذاها مطرح شده است. با این حال، شواهد علمی کافی در مورد اثبات اثرات مضر آنها بر سلامتی انسان و حیوان ارائه نشده است. در عین حال، روش‌های علمی و مدیریتی جدید (فناوری‌ها و مقررات جدید) برای تعدیل برخی خطرات احتمالی زیست محیطی ارائه شده است. برخی چالش‌ها نظیر سازگاری تدریجی آفت‌ها با ژن تغییریافته با به‌کارگیری تکنیک پناهگاه، هرم‌بندی ژن و کاربرد پرایمرهایی که به خوبی با جزء مکمل خود در ساختار ژنتیک جفت می‌شوند به گونه‌ای که نتایج ناخواسته شامل خاموشی ژن، فعال‌سازی یا تغییر ساختار بخش‌های غیرهدف را به حداقل ممکن برساند قابل مرتفع شدن هستند. البته این بدان معنی نیست که در آینده هیچ گونه اثرات مضر شناخته نشود. بنابراین، همواره لازم است پیش از ورود محصولات تراریخته به بازار ارزیابی خطر آنها انجام گرفته و حتی بعد از عرضه آنها پایش مستمر به منظور پیشگیری از مشکلات احتمالی صورت پذیرد. در مجموع، کاربرد ایمن این فناوری و محصولات تراریخته با در نظر گرفتن تمام تفاهم نامه‌های قابل قبول ملی و بین‌المللی ارزیابی خطرات سلامتی و زیست محیطی به بهره‌گیری از فواید این تکنولوژی در کشاورزی، پزشکی و صنعت کمک خواهد کرد. با این حال، ارزیابی‌های سلامت‌سنجی این محصولات همواره در حال انجام می‌باشند.

تعارض منافع: نویسندگان اعلام می‌کنند که هیچ تعارض منافعی وجود ندارد.

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واژگان کلیدی

- خطرات زیست محیطی
- غذاهای اصلاح ژنتیکی شده
- فواید سازواره‌های تراریخته
- خطرات سلامتی
- ارزیابی خطر
- عوامل نگران‌کننده ایمنی

***نویسنده مسئول**

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