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(Review Article)

Journey of genetically modified crops: Status and prospects

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Abstract

Background and Objective: Agricultural biotechnology has major concern with genetic improvement of crops to increase their yields or efficiency, genetic characterization & conservation of plant genetic resources and disease diagnosis. Advance biotechnological techniques help in crop improvement as well as crop productivity. The introgression of different traits into crops was preceded through selection and by rapid development in plant breeding in the 20th century. Transgenic technology helps to develop genetically modified crops which are resistant to abiotic and biotic stresses. Apart from this, the different transgenic crops are commercially released, but some of them are not yet released with traits with special reference to bio-fortification, phytoremediation and production of nutritional value i.e., rice with significant level of zinc and iron nutrients and bananas with vitamins.

Conclusion: The review highlights the present status and future prospects of genetic modified crops and model framework for commercialization need for sustainable agriculture. Apart from that recent technological advancement in the field of genome editing using engineered nucleases has provided new opportunities for development and commercialization of genetic modified plants.

Keywords: Transgenic plants; Major traits; Crop productivity; Genome editing; Sustainable development

1. Introduction

With the exponential increase in world's population, demands for food will become major challenges to human mankind. Now-a-days, food insecurity and malnutrition are considered to be more deadly concerns for human health, leading to high mortality in most of the developing countries [1]. In order to be healthy, our daily diet need must include sufficient high quality of foods along with essential nutrients. To feed the world population, which is continuously increasing and predicted to be 9.9 billion in 2050 and 11.2 billion in 2100, is indeed a major task [2].The yield has been reduced significantly due to change of climate and also other abiotic and biotic stresses. Therefore, to achieve the goal of food security, traditional agricultural practices need to be integrated with advance biotechnological measures. Thus, the idea is to develop the Genetically Modified (GM) genotype having higher potential of crop yield. A GM crop is having one or more genes coding for desirable traits which have been inserted using different methods of genetic engineering. This trait includes the genes for enhancing food production, nutritional and health benefits, environmental condition, fruit storage, and future economic benefits. So, it enhances the availability of food at global and regional levels ensuring food safety and quality. Agricultural biotechnology has proven to be a powerful complement to traditional breeding as it allows access to massive gene pools which can be exploited to impart desirable traits in other agriculturally crops. Modern biotechnological techniques could make plants less vulnerable to biotic and abiotic stresses. This technology

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has also enabled plants to compete efficiently against weeds for soil nutrients by altering their composition.GM crops have also enhanced the economic and social condition of farmers. Hence, GM crops have turned to be an important agricultural innovation system which has been debated controversially due to concerns over human safety, the ecosystem, and biodiversity [1].

Since, the day of first GM crop develop, transgenic technology has been used in different ways to change the architecture of crop plant. However, transgenes integration in the genome is non-specific, sometimes not stable which is a major public concern in case of edible crop plants [3]. In recent times, genome editing technique in plants has paved new pathway for precise gene editing process using site specific nucleases. These nucleases form double-stranded breaks in the target DNA which are repaired through non-homologous end joining or homology-directed recombination resulting in insertion/deletion and substitution mutations in the target DNA [4].This technology leads to random transgenes insertions and quite often random phenotypes, genome editing produces mutants, thus becoming the potential tool in crop improvement. The present review highlighted a summary of various achievements of transgenic technology in crop improvement in present status and future prospects in a changing scenario of technological advancement and consumer acceptance.

2. Status of genetically modified crops

Table 1 Global area of GM crops in 2020: country wise (ISAAA, 2020)

Country	Total area under cultivation (million ha)	Major Genetic modified crops
United States	75.0	Corn, Soybean, Cotton, Canola, Sugar beets, Alfalfa, Papaya, Squash, Potatoes
Brazil	50.2	Soybean, Corn, Cotton
Argentina	23.6	Soybean, Corn, Cotton
India	11.4	Cotton
Canada	13.1	Canola, Corn, Soybean, Sugar beets
China	2.8	Cotton, Papaya, Poplar
Paraguay	3.0	Soybean, Corns, Cotton
Pakistan	3.0	Cotton
South Africa	2.7	Corn, Soya beans, Cotton
Uruguay	1.1	Soybean, Corn
Bolivia	1.3	Soybean
Philippines	0.6	Corn
Australia	0.9	Cotton, Canola
Myanmar	0.3	Cotton
Mexico	0.1	Cotton, Soybean
Spain	0.1	Corn
Colombia	0.1	Cotton, Corn
Sudan	0.2	Cotton
Honduras	<0.1	Corn
Chile	<0.1	Corn, Soybean, Canola
Portugal	<0.1	Corn
Vietnam	<0.1	Corn
Costa Rica	<0.1	Cotton, Soybean
Bangladesh	<0.1	Brinjal /Eggplant

The adoption of genetic modified crops started during 1990s. Since then, the technology rapidly spread around the world including both developed and developing countries (Table 1). Around 26 countries including 21 developing countries and 5 developed countries have planted to produce nearly2.5 billion hectares area globally of genetic modified crops [5].Among the10 top countries with the more cultivation share of the genetic modified plant area are the United States with 75 million hectares (39% of global total), Brazil with 51.3 million hectares (27 %), Argentina with 23.9 million hectares (12%), Canada with 12.7 million hectares (7%), India with 11.6 million hectares (6%), Paraguay with 3.8 million hectares (2%) and China with 2.9 million hectares (2%), Pakistan with 2.8 million hectares(1%), South Africa with 2.7 million hectares (1%)and Uruguay with 1.3 million hectares (1%).Another 16 countries grew a total of approximately 3.7million hectares in 2018 [5]. The global cultivation of GM crops has enhanced nearly 100-fold from 1.7 million hectares in 1996 to 2.5 billion hectares in 2018 and around 18 million farmers have adopted this technology [5].The available data indicate that country like United States, Brazil, and Argentina accounts for more than three-quarters of the total global area. The crops like corn, soybeans, cotton, and canola are mostly exploited through genetic modified technology. The most dominating crop is Bt soybean herbicide tolerant (HT) followed by insect resistant Bt-maize, HT maize and insect resistant cotton with respective shares of 23%, 21% and 10%[6].

As per the data published in ISAAA (International Service for the Acquisition of Agri-biotech Applications, 2018) [5], Brazil ranked second highest in cultivation of biotech crop in the world with 51.3m hectares as compared to USA which ranked first with 75 m hectares. While, India sustains its biotech cotton and become the first Bt cotton producer in the world. The country like India maintained its 5thposition in the world with cultivation of 11.4million hectares including 7.7 million by small farmers with an adoption rate of 95%. On the basis of comprehensive global meta-analysis, about 147 published literatures worldwide confirmed the significant uses of GM crops over the last 25 years [6]. It is concluded that on an average the 37% reduction rate use of pesticides with 22% increase of crop yield and 68% of farmer profit after adoption of GM technology [7]. Efforts are being made to expand the use of GM technology to other major crops within regulatory frameworks of the government. In addition to economic gains, farmers are also benefited by enormous reduction of insecticide/pesticide applications, thereby reducing the cost and mostly contributed to a more sustainable environment with better quality of life. Several beneficial traits had been developed, but few of these were available in commercial crop varieties during 2018. Most commercially available traits in the last 25 years of GM crops were aimed to protect the crop from insect and pest damage. Other types of traits, such as higher nutritional qualities were being studied.

2.1. Involvement of recombinant technology

Introgression of one or more transgenes into the genomes through either genetic engineering or the process of recombinant-DNA technology [8]. Recombinant DNA technology is a process that the genetic material is changed in such a way that does not occur naturally by mating and/or natural recombination [9].The transgenes are genes with known traits or mutated variants of known genes [10].This technology has been used in biological and medical research, production of pharmaceutical drugs, experimental medicine and agriculture. In the course of development in the agricultural biotechnology, a number of genetic modified crops carrying novel traits have been developed and released for commercial production. Initially, four crops such as soybean, maize, cotton and canola with two traits (herbicide and insect resistance) have been released, and many of them are in the pipeline with trait combinations [11]. The use of genetic modified technology in food production has become promising due to high production and improved quality [10]. The crop traits targeted through gene technology are not completely different from those pursued by conventional breeding. Further, these technologies were categories along with the timeline [12].

- First-generation: involve improvements in agronomic traits, such as better resistance to pests and diseases.
- Second-generation: involve enhanced quality traits, such as higher nutrient contents of food products.
- Third-generation: involve plants designed to produce special substances for pharmaceutical or industrial purposes.

In the early 1900s, the first commercially grown genetic modified food crop was the tomato (called FlavrSavr), which was produced by Californian Company Calgene imparting more resistance to rotting.

2.2. Commercialization of genetically modified crops

It has been reported that genetic modified crops were cultivated in 1994 and subsequently, in 1996 about 1.66 million hectares area covered with different genetic traits [6].The USA was one of the first countries to adopt the genetic modified crops such as soybeans, maize, cotton, and canola in 1996. According to the ISAAA reports, Canada and Argentina, now dominating the production of soybeans, maize, and canola in Canada, and maize, cotton, and soybeans in Argentina. Australia, also considered as an early adopter of genetic modify technology in cotton (1996), with genetic modified traits now accounting for almost all cotton production. Among African countries, South Africa was the first to embrace this technology and commercialized in 2000. The technology is widely used in the important crops like maize, soybeans, and cotton. In case of Asia, five countries adapted genetic modified crops. China was the first Asian country to use the genetic modified technology and commercially back in 1997 when genetic modified insect resistant (IR) technology was first used. This technology rapidly expanded with GM virus-resistant papaya in 2008. In India, insect resistant cotton was first adopted in 2002, and its use increased rapidly in subsequent years i.e. 95% of the total area. IR cotton was also planted in Pakistan and Myanmar. Lastly, in the Philippines, IR maize was first adapted commercially in 2003 and then, herbicide tolerant (HT) maize was also adopted in 2006. In South America, there is an interesting tale of adoption of genetic modified technology as it resulted from illegal spread of the technology, across borders into countries which were first reluctant to legalize the use of the technology. Thus, genetic modified-HT soybeans were first grown illegally in the southernmost states of Brazil in 1997, a year after legal adoption in Argentina. In 2003, the Brazilian government legalized the commercial growing of genetic modified-HT soybeans, when more than 10% of the country's soybean crop had been grown using the technology. Similar cases of widespread illegal adoption of GM-HT soybeans occurred in Paraguay and Bolivia before the respective governments authorized the planting of soybean crops. During last 26 years (1996-2022) of the commercialization of biotech crops, it has been confirmed that the genetic modified crops have substantially delivered social benefits to farmers and also improve the environmental, economic and health sectors. The status of commercialized genetic modified crops is presented in Table 2.

3. Application of genetically modified crops

3.1. Herbicide tolerance (HT)

Herbicide tolerance (HT) is one of the important promising traits in GM crops, as it prevents environmental damage by reducing the herbicides requirement. In total, HT crops account for 66% of total GM crops [6]. Crops that are generally tolerant to certain broad-spectrum herbicides such as glyphosate and glufosinate are referred as HT crops. These herbicides are more effective, less toxic, and usually cheaper than selective herbicides. Hence, farmers who adopt HT technology benefit in the application of less herbicide. Monsanto (1996) developed a GM strain of soybean which to be not affected by their herbicide product Roundup. Initially, a large group of farmers grew these soybeans which then only require one application of weed-killer instead of multiple applications, reducing production cost and limiting the dangers of agricultural waste run-off [13]. In 2009, genetic modified-HT soybeans became available to commercial growers in the USA, it offered the similar tolerance to glyphosate as the first generation but with higher yielding potential. However, the weeds are very much tolerant to glyphosate. The growers have faced great problem to grow the genetic modified-HT soybean crops. It was necessary to include use of other herbicides with different/complementary modes of action in combination with glyphosate to address the weed resistance issues. The technology was further developed by Bayer. The gene which imparts tolerance to glufosinate encodes phosphinothricine acetyl transferase (PAT), which detoxifies the herbicides. A number of crops like oilseed rape, maize, soybean, rice, cotton has been modified using this technology. Glufosinate is marketed by Bayer under the trade name Liberty and the improved crop varieties are marketed under the trade name Liberty Link.

3.2. Insect Resistance (IR)

Farmers used maximum quantity of chemical pesticides every year, which is harmful to soil, crop plants, society, and environment. Consumption of pesticides treated food also creates great potential to health hazards. The run-off of agricultural wastes from excessive use of pesticides and fertilizers can damage the deep water supply and cause harm to the environment. Farmers were enormously benefited by cultivating the genetic modified-insect resistant (IR) crops, i.e. at least a 50% reduction in the number of insecticide applications, thereby reducing farmer exposure to insecticides and more importantly contributed to the sustainable environment and better quality of life. It was also observed that the crop yield gains and pesticide reductions are maximum for the insect resistant crops rather than for herbicide tolerant crops [14]. The success of the insect resistance in crop plants is epitomized by the insecticidal Bt toxins produced by *Bacillus thuringiensis (Bt)*, a soil bacterium [15].Each Bt gene is active against a specific range of insects thus minimizes direct impact on other non target organisms. The first engineered crops expressing Bt toxins were commercially approved in the United States in 1995 and subsequently in 2016, Bt corn and Bt cotton accounted for 79% and 84% of US acreage for corn and cotton, respectively [16]. In India, IR-Bt Cotton has been used for commercial plantation. India continued to be the largest biotech cotton producing country in the world with 11.4million hectares planted by 7.7 million small farmers with an adoption rate of 95% [5]. The European Union (EU) has also allowed commercial cultivation of insect-resistant maize (MON810) developed by Monsanto. Several other Bt crops are in the way of release. For example, Bt-brinzal resistant to lepidopteran (*Leucinodes orbonalis*) was commercially approved in Bangladesh in 2013. In India has also tested field trials of IR chickpea and pigeon pea in 2016 [17]. RNA interference (RNAi) is another technology which offers greater opportunity than protein toxins to design insecticides. Insecticidal RNAi against the western corn rootworm in corn is advancing through the regulatory process in the United States [18].

3.3. Disease Resistance (DR)

In recent time, most of the agricultural researchers have developed the disease resistant crop plants caused by viruses, fungi, and bacteria [19,20]. Potato is an important global crop, up to 70% of attainable potato production could potentially be lost due to pests such as colorado beetle and virus vectors like aphids and leaf hoppers, including potato virus Y (PVY) and potato leaf roll virus (PLRV) as well as nematodes. Global yield loss in potatoes due to different pathogens is estimated at 22% for fungal, 8% for viruses, 18% for insect pests, and 23% for weeds. Thus, potato suffers very high losses from pests and diseases, which can be effectively controlled by the modern biotechnological tools. The single most important disease, accounting for 15% of potato yield losses caused by the fungus *Phytophthora infestans*. The conventional technology has still failed to confer resistance. In 2015, GMcropwith improved multi-trait potato, developed by Simplot, was first commercialized in 160 hectares; an improved version, Innate™ 2 was also approved in 2015, and also added resistance to the fungal disease. Other approaches have been developed to engineer fungal resistance into crop plants by modifying with the genes that express fungicidal proteins. The genes encoding the enzymes like chitinase and ß-glucanase have been successfully engineered in transgenic plants [21,22]. Plant resistance to virus can also been achieved by knockdown the activity of viral genes. Monsanto used this technique to develop potato against Potato leaf roll virus (PLRV) by blocking the expression of the viral replicate gene [23]. China has approved for the commercial cultivation of virus-resistant papaya, tomato, and sweet pepper. Brazil has also approved for commercial cultivation of virus resistant common bean against bean golden mosaic virus [24]. Kenya has also tested the virus resistant sweet potato and cassava against feathery mottle virus and cassava mosaic virus respectively in the field. However, these crops have not been approved for commercial cultivation.

3.4. Abiotic Stress Tolerance

The additional new challenges in agriculture are associated with climate change, such as high temperature, cold, drought, and salinity. As the underlying genetic mechanisms of abiotic stress are complex, the work is at a more basic level, so commercial releases of varieties are comparatively slow as reported [25,26]. Droughts, flood and temperature changes are predicted to become more prevalent and more severe. Therefore, there will be an urgent need for developing the varieties which can be well adapted to climatic conditions. About 70% of fresh water is currently used by agriculture globally, and this is obviously not sustainable in the future as the population increases by almost 30% to over 9.6 billion by 2050. Developing plants that can withstand long periods of drought or high salt content in soil and groundwater will help people to grow crops in formerly inhospitable places [27,28].Drought tolerance (DT) is expected to have a major impact on more sustainable cropping systems worldwide, particularly in developing countries, where drought will likely be more prevalent and severe in industrial countries. The first biotech maize hybrids (Drought Gard™ tolerant maize) with a degree of drought tolerance were commercialized in 2013 in the USA and increased more than 15-fold from 50,000 hectares to 810,000 hectares, reflecting high farmer acceptance at 3-fold year-to-year between 2014 and 2015. The same, DroughtGard™ (MON 87460), was donated by Monsanto to the Public-Private Partnership (PPP) mode, aimed at delivering biotech drought tolerant maize to selected tropical countries in Africa by 2017. Similarly, for low temperature areas in order to withstand cold and chilling injury which would damage the seedlings, an antifreeze gene from cold water fish has been introduced into tobacco and potato [29]. Hence, plant tolerance to abiotic stress is also being worked on intensively.

3.5. Nutrition improvement

The second-generation genetic modified foods in underlies include product quality improvements for nutrition and industrial purposes. Quality improvement is almost necessary as malnutrition is most common human beings in third world countries where impoverished peoples rely on a single crop such as rice for the main staple of their diet. However, rice does not contain adequate amounts of all necessary nutrients to prevent malnutrition. Introducing food crops with enrichment of nutrients, vitamins and mineral contents through conventional or transgenic breeding is noted as 'Biofortification'. This technology helps in alleviating nutrient deficiencies. For example, of a GM biofortified crop is golden rice, which contains significant amounts of pro-vitamin-A to cure night blindness [30,31,32], and has been developed with β-carotene expression in the rice endosperm [33]. In the meantime, International Rice Research Institute, Philippines used the trait into mega varieties, and confined field tests in the Philippines and also field trial has been approved in Bangladesh [14]. Super bananas developed by transforming a phytoene synthase (PSY2a) gene with increased level of β-carotene are under human trials [34]. It has an added advantage over rice is that being sterile, there is no concern about movement of transgenes. Other crop biofortification projects including genetic modified sorghum, cassava, banana, and rice enhanced with multiple nutrients [35]. These crops become commercially available over the time. Beside rice, few other crops are also genetically improved for obtaining better oilseeds with improved fatty acid profiles, high-amylose maize, high oil yield particularly canola, staple foods with enhanced contents of essential amino acids, minerals, and vitamins and other genetic modified functional foods with diverse health benefits [36, 37].

3.6. Pharmaceuticals

The third-generation GM crops concentrate on molecular farming where the plants are used to produce pharmaceutical products such as monoclonal antibodies and vaccines or diagnostic enzymes as well as biodegradable plastics [38].The researchers are developing genetic modified fruit crops such as tomatoes, banana and potatoes and used as edible vaccines and also better storability [39,40]. As compared to microorganisms and animal cell cultures, plant cell cultures can be cultivated as intact, multi-cellular organisms in a sterile condition and for large scale production metabolites. The main significant is that the pharmaceutical crops can be grown on large scale as agricultural food crops allowing the maximal production of recombinant protein according to market demand [41,42]. These medicines will be much easier to shifting, store and administer than the traditional one. A Texas based company Prodi-Gene has engineered tobacco to produce a monoclonal antibody Guy's13 [43] and transferred the technology to a California based company Planet Biotechnology Inc. where the product is undergoing clinical trials under the product name CaroRxTM. Prodi-Gene has also engineered maize to produce bovine trypsin and is marketing the enzyme under the trade name TrypZean [44]. Although the concept for edible vaccines was developed, product development and their regulatory mechanisms are even more complex than the first and second generation.

3.7. Biosafety concerns

The introductions of foreign genes into edible plants, that it may have an unexpected and negative impact on human health are growing every day. As a result of inserting genes, from other sources which have never been eaten as food, new proteins with unexpected functions may introduce into human and animal food chains. This gene can behave in different ways in different locations, depending on the regulatory elements it ends up next to. The process of inserting the gene can damage the plant's own DNA [45].As genetic engineers cannot control where the genes take its position in the plant DNA and also do not identify the effects of the different locations, unpredicted effects can easily occur [46]. So, a harmless protein of an organism can behave as harmful if inserted into another organism, even if its sequence of amino acids remains completely identical. The reason behind it is the molecular mechanism called post-translational modification, where different sugars, lipids or other molecules attach to the protein and modify its function [47]. The safety testing of GM foods is based on the concept of 'substantial equivalence', i.e. a genetic modified food should substantially be the same as a non-GM food then it is considered to be safe [48]. This includes comparing of the crop phenotypic, genotypic, and agronomical and its compositional properties with the traditionally produced food, and then establishes the degree of equivalence between the two counterparts. Further, toxicological, analytical and nutritional investigations should be carried out by keeping in mind the key nutrients like protein, carbohydrates, fats, fatty acids, vitamins and other nutritional / anti-nutritional compounds that are generally measured to study the impact on nutritional value and safety of the organisms [49].

3.8. Health risks

There is a possibility that introducing a new gene into a plant may create a new allergen or cause an allergic reaction in susceptible individuals. The incorporation of a gene from brazil nuts into soybeans was abandoned because it caused unexpected allergic reactions [50]. GM crop, StarLink corn which was engineered to introduce Bt that is an effective against Lepidopteran insect [46]. The U.S. Centre for disease control and prevention has evaluated the allergen effects of StarLink corn. The proteins expressed in genetic modified crops are the Cry-protein strains that have insecticidal properties for larvae of herbivore insect species [51]. The mechanism of action of cry-proteins is based on specific receptor binding, in susceptible insect larvae, in epithelial cells of the mid-gut, leading to pore formation, cell lyses', disintegration of the epithelium lining in the mid-gut and, eventually, to death of the larvae owing to starvation. The insertion of transgene (s) encoding new protein(s) or other constituents may cause unintended pleiotropic effects by changing the levels and activities of inherent enzymes, nutrients and metabolites [49,52]. In case of the transgenic rice, containing the soybean glycine gene exhibited a 20% increase in protein content due to elevated glycine and a 50% increase in vitamin-B6 [53]. Most of the genetic modified crops contain genes which provide resistance to ampicillin, kanamycin and rifampicin for the screening of transformed product. Kuiper et al [49] reported that there are chances of these genes could be passed from food to bacteria in the guts of humans and animals. So, they have used a model of a human gut to study the effects of GM food after ingestion in human body. They have predicted that 6% of the genes from genetic modified tomatoes would survive digestion in the gut and considered that the genes could survive for long enough time for bacteria to pick them up. Similarly, viral genes that are generally inserted into disease resistant crops produce viral proteins which may suppress the immune system of human body against viral infections, particularly in the gut region. The gut microorganisms can produce large amounts of potentially harmful proteins if the viral genes can get entry inside these organisms. They also observed that the transfer of GM material into the unborn fetus through the placenta or integrates into adult sex cells and has the capacity to alter the genetic constitution of the future generations. Moreover, the gene introduced into the potatoes for insect resistance was a snowdrop flower lectin, a substance known to be toxic to mammals.

3.9. Environmental risks

The environment is the one of the serious concern for the living society. It is of unintended pollen transfer among the genetic modified and non-genetic modified plant species. Cowgill *et al* [54] noted that aphids feeding on nematode-tolerant genetic modified crops, expressing nematode proteinase inhibitors may damage different natural enemies of aphids. The populations of aphids also adversely affected. When highly tolerant crops are grown on a large scale, the abundance of some natural enemies may also decline due to prey depletion [55]. Gene transfer to non-target species was another concern that crop plants engineered for herbicide tolerance and weeds will cross-breed, resulting in the transfer of the herbicide resistance genes from the crops into the weeds. This resulted into "superweeds" that show herbicide tolerance as well. Other introduced genes may cross over into non-modified crops planted next to genetic modified crops; so, create the environmental biosafety issues, as transgenic escape from a genetic modified crop genotype to its non-genetic modified crop counterparts or wild relatives. The transgenic escape of rice from its wild varieties via pollen-mediated gene flow has some unwanted ecological consequences. The quantity or nutritional quality of non-prey foods such as vegetative tissue, seeds, pollen, floral and extra floral nectar, and honeydew may also be influenced by transgenes, and thus affect natural enemies that rely upon these foods. For instance, nectar production and sugar content are also sometimes altered in genetic modified crops from that observed in non-genetic modified counterparts as reported by Picard-Nizou *et al* [56].

4. New Breeding Technologies

Several biotech techniques, including plant tissue culture, disease diagnostics, genomics, marker-assisted selection (MAS) etc have been used for crop production program (Figure 1).They are used collectively for 'speeding the breeding' and help to mitigate the effects of climate change. There are several genetic modified protocols on various crops with different traits have been reported (Table 2). Twenty years after the commercialization of biotech crops, the scientific global community is again eager about the potential of a new crop biotechnology tool called "genome or gene editing". Experts believed that potentially of the "real power" of these new breeding technologies is their ability to 'edit' and modify single or multiple native plant genes, coding for important traits such as drought, cold or salinity and generating useful improved crops that are not transgenic. The newly advanced budding and promising biotech applications such as Zinc Finger Nucleases (ZFN) technology [57], Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR)-associated nuclease systems [58,59] and Transcription Activator-Like Effector Nucleases (TALENs), are being used to increase the efficiency and precision of the transformation process [60]. US regulatory systems have initially suggested that there will have a very noteworthy impact on the competence and timing of the current resource-intensive regulation/approval process and the acceptance of the products by the public. Among diverse non-transgenic technologies, CRISPR was judged to be most promising. These allow the cutting of the DNA at a pre-determined location and the precise insertion of the mutation or single nucleotide changes at an optimal location in the genome for maximum expression. For example, powdery mildew-resistant wheat developed by the Chinese Academy of Sciences researchers through TALENs and CRISPR tools. The researchers deleted genes encoding for proteins that repress defenses against the mildew. Products already under development using the above technologies include all the major food and feed crops: canola (herbicide tolerance), maize (drought tolerance), wheat (disease resistance and hybrid technology), soybean (oil quality), rice (disease resistance), potato (improved storage qualities), tomato (fruit ripening), and peanuts (allergen-free). More complex traits, coded by multiple genes, like improved photosynthetic ability are planned for the future, which may be closer than the expected. CRISPR technology earned the Science's 2015 "Breakthrough of the Year Laurels". Another class of new applications is Plant Membrane Transporters (PMT)that is being researched vibrantly to overcome a range of crop constraints arising from abiotic and biotic stresses for enrichment of micronutrients. Recent studies show that specialized PMT can be used to enhance yields of staple crops, enhance resistance to salinity, drought, insect, disease, etc. and augment micronutrient content.

Table 2 Status of commercialized GM Crops. Data compiled from http://www.isaaa.org/gmapprovaldatabase/default.asp.

Trait type	Crop	Trait description	Event Name	Trade Name	Developer	Availability
Abiotic Stress Tolerance	Maize	Drought stress tolerance	MON87460	Genuity® DroughtGard™	Monsanto Company and BASF	Authorised (also for cultivation)
	Soybean	Drought stress tolerance	HB4	Verdeca HB4 Soybean	Verdeca	Authorised (also for cultivation)
	Sugarcane	Drought stress tolerance	NXI-4T	not available	PT Perkebunan Nusantara XI (Persero)	Authorised (Food/Feed)
Altered Growth/Yield	Eucalyptus	Volumetric Wood Increase	H421	GM Eucalyptus	FuturaGene Group	Authorised (also for cultivation)
	Maize	Increased Ear Biomass	MON87403	not available	Monsanto Company	Authorised (also for cultivation)
	Soybean	Enhanced Photosynthesis/Yield	MON87712	not available	Monsanto Company	Authorised (also for cultivation)
Disease Resistance	Bean	Viral disease resistance	EMBRAPA 5.1	not available	EMBRAPA (Brazil)	Authorised (also for cultivation)
	Papaya	Viral disease resistance	55-1	Rainbow, SunUp	Cornell University and University of Hawaii	Authorised (also for cultivation)
	Papaya	Viral disease resistance	Huanong No. 1	Huanong No. 1	South China Agricultural University	Authorised (also for cultivation)
	Papaya	Viral disease resistance	X17-2	not available	University of Florida	Authorised (also for cultivation)
	Plum	Viral disease resistance	C-5	not available	United States Department of Agriculture - Agricultural Research Service	Authorised (also for cultivation)
	Potato	Viral disease resistance	TIC-AR233-5	not available	Technoplant Argentina	Authorised (also for cultivation)

	Squash	Viral disease resistance	CZW3	not available	Seminis Vegetable Seeds (Canada) and Monsanto Company (Asgrow)	Authorised (also for cultivation)
	Squash	Viral disease resistance	ZW20	not available	Seminis Vegetable Seeds (Canada) and Monsanto Company (Asgrow)	Authorised (also for cultivation)
	Sweet pepper	Viral disease resistance	PK-SP01	not available	Beijing University	Authorised (also for cultivation)
	Tomato	Viral disease resistance	PK-TM8805R (8805R)	not available	Beijing University	Authorised (also for cultivation)
Herbicide Tolerance	Alfalfa	Glyphosate herbicide tolerance	J101	Roundup Ready™ Alfalfa	Monsanto Company and Forage Genetics International	Authorised (also for cultivation)
	Canola	Glyphosate herbicide tolerance	61061	not available	DuPont (Pioneer Hi-Bred International Inc.)	Authorised (also for cultivation)
	Canola	Glyphosate herbicide tolerance	73496	Optimum® Gly canola	DuPont (Pioneer Hi-Bred International Inc.)	Authorised (also for cultivation)
	Canola	Glyphosate herbicide tolerance	GT200 (RT200)	Roundup Ready™ Canola	Monsanto Company	Authorised (also for cultivation)
	Canola	Glyphosate herbicide tolerance	HCN10 (Topas 19/2)	Liberty Link™ Independence™	Bayer Crop Science	Authorised (also for cultivation)
	Canola	Glufosinate herbicide tolerance	HCN28 (T45)	InVigor™ Canola	Bayer Crop Science	Authorised (also for cultivation)
	Canola	Glufosinate herbicide tolerance	HCN92 (Topas 19/2)	Liberty Link™ Innovator™	Bayer CropScience	Authorised (also for cultivation)
	Canola	Glyphosate herbicide tolerance	MON88302	TruFlex™ Roundup Ready™ Canola	Monsanto Company	Authorised (also for cultivation)

	Canola	Oxynil herbicide tolerance	OXY-235	Navigator™ Canola	Bayer Crop Science	Authorised (also for cultivation)
	Cotton	Sulfonylurea herbicide tolerance	19-51a	not available	DuPont	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, 2,4-D herbicide tolerance	81910	not available	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Cotton	Oxynil herbicide tolerance	BXN10211 (10211)	BXN™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Glyphosate herbicide tolerance	GHB614	GlyTol™	Bayer Crop Science	Authorised (also for cultivation)
	Cotton	Glyphosate herbicide tolerance, Isoxaflutole herbicide tolerance	GHB811	not available	Bayer Crop Science	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance	LLCotton25	Fibermax™ Liberty Link™	Bayer Crop Science	Authorised (also for cultivation)
	Cotton	Glyphosate herbicide tolerance	MON1445	Roundup Ready™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, Dicamba herbicide tolerance	MON88701	not available	Monsanto Company	Authorised (also for cultivation)
	Cotton	Glyphosate herbicide tolerance	MON88913	Roundup Ready™ Flex™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Creeping Bentgrass	Glyphosate herbicide tolerance	ASR368	Roundup Ready™ Creeping Bentgrass	Monsanto Company and Scotts Seeds	Authorised (also for cultivation)
	Flax	Sulfonylurea herbicide tolerance	FP967 (CDC Triffid)	CDC Triffid Flax	University of Saskatchewan	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance, Sulfonylurea herbicide tolerance	98140	Optimum™ GAT™	DuPont	Authorised (also for cultivation)

	Maize	2,4-D herbicide tolerance	DAS40278	Enlist™ Maize	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance	DLL25 (B16)	not available	Monsanto Company	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	GA21	Roundup Ready™ Maize, Agrisure™GT	Monsanto Company	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	HCEM485	not available	Stine Seed Farm, Inc (USA)	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	MON832	Roundup Ready™ Maize	Monsanto Company	Authorised (Food)
	Maize	Glufosinate herbicide tolerance, Dicamba herbicide tolerance	MON87419	not available	Monsanto Company	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	MON87427	Roundup Ready™ Maize	Monsanto Company	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Glyphosate herbicide tolerance	MZHG0JG	not available	Syngenta	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	NK603	Roundup Ready™ 2 Maize	Monsanto Company	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance	T14	Liberty Link™ Maize	Bayer Crop Science	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance	VCO-01981-5	not available	Genective S.A.	Authorised (also for cultivation)
	Rice	Glufosinate herbicide tolerance	LLRICE06	Liberty Link™ rice	Bayer Crop Science	Authorised (also for cultivation)
	Soybean	Glufosinate herbicide tolerance	A2704-12	Liberty Link® soybean	Bayer Crop Science	Authorised (also for cultivation)
	Soybean	Sulfonylurea herbicide tolerance	CV127	Cultivance	BASF	Authorised (also for cultivation)

	Soybean	Glufosinate herbicide tolerance, Glyphosate herbicide tolerance, 2,4-D herbicide tolerance	DAS44406-6	not available	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Soybean	Glufosinate herbicide tolerance, 2,4-D herbicide tolerance	DAS68416-4	Enlist™ Soybean	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Soybean	Glyphosate herbicide tolerance, Sulfonylurea herbicide tolerance	DP356043	Optimum GAT™	DuPont	Authorised (also for cultivation)
	Soybean	Glyphosate herbicide tolerance	GTS 40-3-2 (40-3-2)	Roundup Ready™ soybean	Monsanto Company	Authorised (also for cultivation)
	Soybean	Glufosinate herbicide tolerance	GU262	Liberty Link™ soybean	Bayer Crop Science	Authorised (also for cultivation)
	Soybean	Glyphosate herbicide tolerance, Dicamba herbicide tolerance	MON87708	Genuity® Roundup Ready™ 2 Xtend™	Monsanto Company	Authorised (also for cultivation)
	Soybean	Glyphosate herbicide tolerance	MON89788	Genuity® Roundup Ready 2 Yield™	Monsanto Company	Authorised (also for cultivation)
	Soybean	Glufosinate herbicide tolerance, Mesotrione Herbicide Tolerance	SYHT0H2	Herbicide-tolerant Soybean line	Bayer Crop Science and Syngenta	Authorised (also for cultivation)
	Soybean	Glufosinate herbicide tolerance	W62	Liberty Link™ soybean	Bayer CropScience and Syngenta	Authorised (also for cultivation)
	Sugar Beet	Glyphosate herbicide tolerance	GTSB77 (T9100152)	InVigor™ sugarbeet	Novartis Seeds and Monsanto Company	Authorised (also for cultivation)
	Sugar Beet	Glyphosate herbicide tolerance	H7-1	Roundup Ready™ sugar beet	Monsanto Company	Authorised (also for cultivation)

	Sugar Beet	Glufosinate herbicide tolerance	T120-7	Liberty Link™ sugarbeet	Bayer Crop Science	Authorised (also for cultivation)
	Tobacco	Oxynil herbicide tolerance	C/F/93/08-02	not available	SEITA S.A. (France)	Authorised (Feed)
	Wheat	Glyphosate herbicide tolerance	MON71800	Roundup Ready™ wheat	Monsanto Company	Sales ended
Insect Resistance	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	281-24-236	not available	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	3006-210-23	not available	Dow Agro Sciences LLC	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	BNLA-601	not available	Central Institute for Cotton Research and University of Agricultural Sciences Dharwad (India)	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	COT102 (IR102)	VIPCOT™ Cotton	Syngenta	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	COT67B (IR67B)	not available	Syngenta	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	Event1	JK 1	JK Agri Genetics Ltd (India)	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	GFM Cry1A	not available	Nath Seeds/Global Transgenes Ltd (India)	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	GK12	not available	Chinese Academy of Agricultural Sciences	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	MLS 9124	not available	Metahelix Life Sciences Pvt. Ltd (India)	Authorised (also for cultivation)

	Cotton	Lepidopteran insect resistance	MON1076	Bollgard™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	MON15985	Bollgard II™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	MON531	Bollgard™ Cotton, Ingard™	Monsanto Company	Authorised (also for cultivation)
	Cotton	Lepidopteran insect resistance	MON757	Bollgard™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Hemipteran Insect Resistance	MON88702	not available	Monsanto Company	Authorised (Food)
	Cotton	Lepidopteran insect resistance, Multiple insect resistance	SGK321	not available	Chinese Academy of Agricultural Sciences	Authorised (also for cultivation)
	Eggplant	Lepidopteran insect resistance	Bt Brinjal Event EE1	BARI Bt Begun-1, -2, -3 and -4	Maharashtra Hybrid Seed Company (MAHYCO)	Authorised (also for cultivation)
	Maize	Multiple insect resistance	5307	Agrisure® Duracade™	Syngenta	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MIR162	Agrisure™ Viptera	Syngenta	Authorised (also for cultivation)
	Maize	Coleopteran insect resistance	MIR604	Agrisure™ RW	Syngenta	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MON801 (MON80100)	not available	Monsanto Company	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MON802	not available	Monsanto Company	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MON809	not available	Monsanto Company and Dupont	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MON810	YieldGard™, MaizeGard™	Monsanto Company	Authorised (also for cultivation)

	Maize	Coleopteran insect resistance	MON863	YieldGard™ Rootworm RW, MaxGard™	Monsanto Company	Authorised (also for cultivation)
	Maize	Lepidopteran insect resistance	MON89034	YieldGard™ VT Pro™	Monsanto Company	Authorised (also for cultivation)
	Poplar	Lepidopteran insect resistance	Bt poplar, poplar 12 (Populus nigra)	not available	Research Institute of Forestry (China)	Authorised (also for cultivation)
	Poplar	Lepidopteran insect resistance, Multiple insect resistance	Hybrid poplar clone 741	not available	Research Institute of Forestry (China)	Authorised (also for cultivation)
	Potato	Coleopteran insect resistance	1210 amk	Lugovskoi plus	Centre Bioengineering, Russian Academy of Sciences	Authorised (Food)
	Potato	Coleopteran insect resistance	2904/1 kgs	Elizaveta plus	Centre Bioengineering, Russian Academy of Sciences	Authorised (Food)
	Potato	Coleopteran insect resistance	ATBT04-27	Atlantic NewLeaf™ potato	Monsanto Company	Authorised (also for cultivation)
	Potato	Coleopteran insect resistance	BT06	New Leaf™ Russet Burbank potato	Monsanto Company	Authorised (also for cultivation)
	Potato	Coleopteran insect resistance	SPBT02-5	Superior NewLeaf™ potato	Monsanto Company	Authorised (also for cultivation)
	Rice	Lepidopteran insect resistance	GM Shanyou 63	BT Shanyou 63	Huazhong Agricultural University (China)	Authorised (also for cultivation)
	Rice	Lepidopteran insect resistance	Huahui-1/TT51-1	Huahui-1	Huazhong Agricultural University (China)	Authorised (also for cultivation)

	Rice	Lepidopteran insect resistance	Tarom molaii + cry1Ab	not available	Agricultural Biotech Research Institute (Iran)	Authorised (also for cultivation)
	Soybean	Lepidopteran insect resistance	DAS81419	not available	Dow AgroSciences LLC	Authorised (also for cultivation)
	Soybean	Lepidopteran insect resistance	MON87701	not available	Monsanto Company	Authorised (also for cultivation)
	Soybean	Lepidopteran insect resistance	MON87751	not available	Monsanto Company	Authorised (also for cultivation)
	Sugarcane	Lepidopteran insect resistance	CTB141175/01-A	not available	Centro de Tecnologia Canavieira (CTC)	Authorised (also for cultivation)
	Sugarcane	Lepidopteran insect resistance	CTC91087-6	not available	Centro de Tecnologia Canavieira (CTC)	Authorised (also for cultivation)
	Tomato	Lepidopteran insect resistance	5345	not available	Monsanto Company	Authorised (also for cultivation)
Modified Product Quality	Alfalfa	Altered lignin production	KK179	HarvXtra™	Monsanto Company and Forage Genetics International	Authorised (also for cultivation)
	Apple	Non-Browning Phenotype	GD743	Arctic™ "Golden Delicious" Apple	Okanagan Specialty Fruits Incorporated	Authorised (also for cultivation)
	Apple	Non-Browning Phenotype	GS784	Arctic™	Okanagan Specialty Fruits Incorporated	Authorised (also for cultivation)
	Apple	Non-Browning Phenotype	NF872	Arctic™ Fuji Apple	Okanagan Specialty Fruits Incorporated	Authorised (also for cultivation)
	Canola	Modified oil/fatty acid	23-18-17 (Event 18)	Laurical™ Canola	Monsanto Company	Authorised (also for cultivation)
	Canola	Modified oil/fatty acid	DHA Canola	not available	Nuseed Pty Ltd	Authorised (also for cultivation)

	Canola	Phytase production	MPS961	Phytaseed™ Canola	BASF	Authorised (Food/Feed)
	Carnation	Modified flower color	11 (7442)	Moondust™	Florigene Pty Ltd. (Australia)	Authorised (also for cultivation)
	Maize	Modified alpha amylase	3272	Enogen™	Syngenta	Authorised (also for cultivation)
	Maize	Phytase production	BVLA430101	not available	Origin Agritech (China)	Authorised (also for cultivation)
	Maize	Modified amino acid	LY038	Mavera™ Maize	Renessen LLC (Netherlands)	Authorised (also for cultivation)
	Melon	Delayed ripening/senescence	Melon A	not available	Agritope Inc. (USA)	Authorised (Food)
	Potato	Modified starch/carbohydrate	AM04-1020	Starch Potato	BASF	Authorised (Food/Feed)
	Potato	Lowered Free Asparagine, Reduced Black Spot, Lowered Reducing Sugars	E12	Innate® Cultivate	J.R. Simplot Co.	Authorised (also for cultivation)
	Rice	Enhanced Provitamin A Content	Provitamin A Biofortified Rice	Golden Rice	International Rice Research Institute	Authorised (Food)
	Safflower	Modified oil/fatty acid	Event 26	not available	Go Resources Pty Ltd	Authorised (also for cultivation)
	Soybean	Modified oil/fatty acid	260-05 (G94-1, G94-19, G168)	not available	DuPont	Authorised (also for cultivation)
	Soybean	Modified oil/fatty acid	DP305423	Treus™, Plenish™	DuPont	Authorised (also for cultivation)
	Tobacco	Nicotine reduction	Vector 21-41	not available	Vector Tobacco Inc. (USA)	Authorised (also for cultivation)
	Tomato	Delayed ripening/senescence	1345-4	not available	DNA Plant Technology Corporation (USA)	Authorised (also for cultivation)
	Tomato	Delayed fruit softening	FLAVR SAVR™	FLAVR SAVR™	Monsanto Company	Authorised (also for cultivation)

Insect Resistance + Disease Resistance	Potato	Coleopteran insect resistance, Viral disease resistance	HLMT15-15	Hi-Lite NewLeaf™ Y potato	Monsanto Company	Authorised (Food/Feed)
	Potato	Coleopteran insect resistance, Viral disease resistance	RBMT15-101	New Leaf™ Y Russet Burbank potato	Monsanto Company	Authorised (also for cultivation)
	Potato	Coleopteran insect resistance, Viral disease resistance	RBMT21-129	New Leaf™ Plus Russet Burbank potato	Monsanto Company	Authorised (also for cultivation)
	Potato	Coleopteran insect resistance, Viral disease resistance	SEMT15-02	Shepody NewLeaf™ Y potato	Monsanto Company	Authorised (also for cultivation)
Disease Resistance + Modified Product Quality	Potato	Lowered Free Asparagine, Reduced Black Spot, Lowered Reducing Sugars , Foliar Late Blight Resistance	X17	Innate® Acclimate	J.R. Simplot Co.	Authorised (also for cultivation)
	Potato	Lowered Free Asparagine, Reduced Black Spot, Lowered Reducing Sugars, Foliar Late Blight Resistance	Y9	Innate® Hibernate	J.R. Simplot Co.	Authorised (also for cultivation)
Herbicide Tolerance + Insect Resistance	Cotton	Oxynil herbicide tolerance, Lepidopteran insect resistance	31707	BXN™ Plus Bollgard™ Cotton	Monsanto Company	Authorised (Food/Feed)
	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	GHB119	not available	Bayer CropScience	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	T303-3	not available	Bayer CropScience	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	33121	not available	DuPont	Not aapproved

	Maize	Glufosinate herbicide tolerance, Coleopteran insect resistance, Lepidopteran insect resistance	4114	not available	DuPont	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Coleopteran insect resistance	59122	Herculex™ RW	Dow AgroSciences LLC and DuPont	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	Bt10	Bt10	Syngenta	Authorised (Food)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	Bt11 (X4334CBR, X4734CBR)	Agrisure™ CB/LL	Syngenta	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	Bt176 (176)	NaturGard KnockOut™, Maximizer™	Syngenta	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	CBH-351	Starlink™ Maize	Bayer CropScience	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	DBT418	Bt Xtra™ Maize	Monsanto Company	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance, Coleopteran insect resistance	MON87411	not available	Monsanto Company	Authorised (also for cultivation)
	Maize	Glyphosate herbicide tolerance, Coleopteran insect resistance	MON88017	YieldGard™ VT™ Rootworm™ RR2	Monsanto Company	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Coleopteran insect resistance, Multiple insect resistance	MZIR098	not available	Syngenta	Authorised (also for cultivation)

	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	TC1507	Herculex™ I, Herculex™ CB	Dow AgroSciences LLC and DuPont	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Lepidopteran insect resistance	TC6275	not available	Dow AgroSciences LLC	Authorised (also for cultivation)
	Cotton	Oxynil herbicide tolerance, Lepidopteran insect resistance	31803	BXN™ Plus Bollgard™ Cotton	Monsanto Company	Authorised (Food/Feed)
	Cotton	Oxynil herbicide tolerance, Lepidopteran insect resistance	31807	BXN™ Plus Bollgard™ Cotton	Monsanto Company	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	GHB119	not available	Bayer CropScience	Authorised (also for cultivation)
	Cotton	Glufosinate herbicide tolerance, Lepidopteran insect resistance	T304-40	not available	Bayer CropScience	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Coleopteran insect resistance, Lepidopteran insect resistance	4114	not available	DuPont	Authorised (also for cultivation)
	Maize	Glufosinate herbicide tolerance, Coleopteran insect resistance	59122	Herculex™ RW	Dow AgroSciences LLC and DuPont	Authorised (also for cultivation)
Herbicide Tolerance + Insect Resistance + Disease Resistance	Potato	Glyphosate herbicide tolerance, Coleopteran insect resistance, Viral disease resistance	RBMT22-082	New Leaf™ Plus Russet Burbank potato	Monsanto Company	Authorised (also for cultivation)
Herbicide Tolerance + Modified Product Quality	Soybean	Glyphosate herbicide tolerance, Modified oil/fatty acid	MON87705	Vistive Gold™	Monsanto Company	Authorised (also for cultivation)

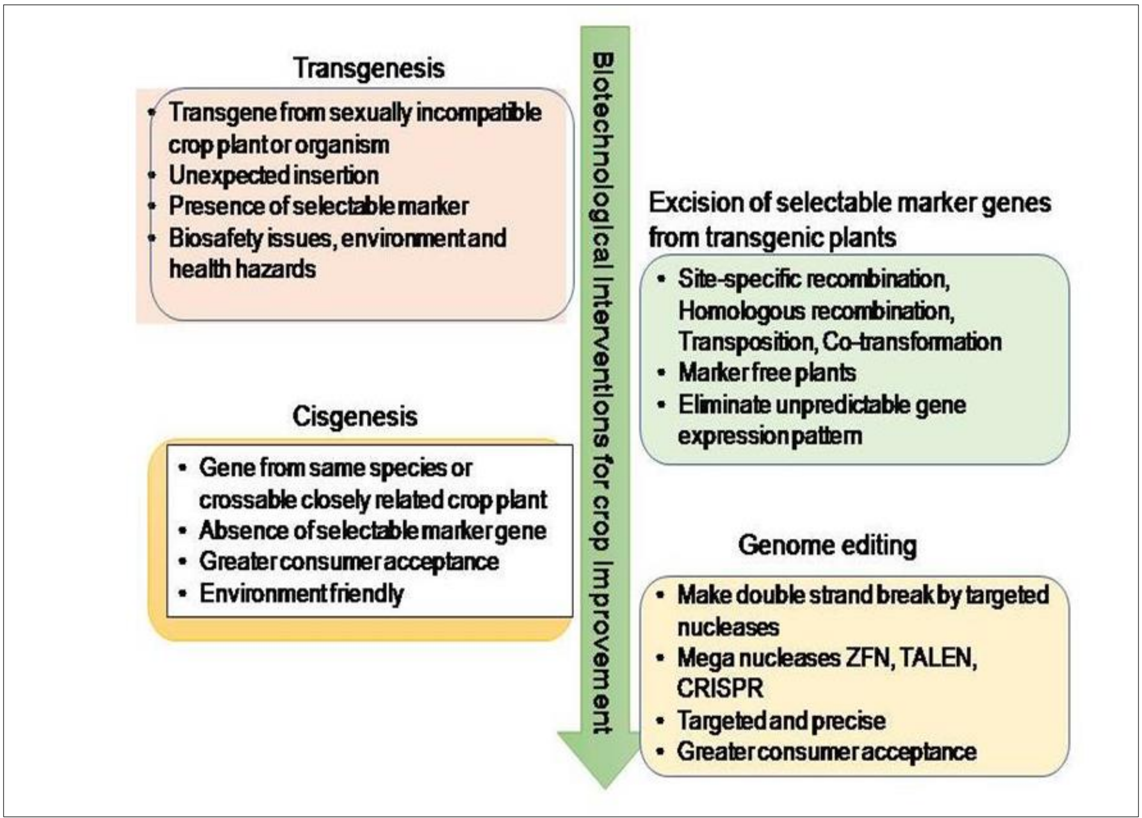

Figure 1 biotechnological intervention for engineering crops towards greater consumer acceptance

5. Exemplary Model for Adoption of Genetically Modified Crops

Bangladesh is one of the smaller Asian countries in the world, which acted as an exemplary model as the fastest country for the adoption of the genetic modified crop. Bangladesh approved Bt-brinjal for the first time on 30 October 2013, and in record time (less than 100 days after approval) the small farmer groups commercialized Bt-brinjal on 22 January 2014.The Bt-brinjal was grown by 27,000 farmers on 2400 hectares in 2017 compared with 2,500 farmers on 700 hectares in 2016, which was a 242% increase in adoption rate of Bt-brinjal cultivation in Bangladesh [61]. So, it represents an excellent adoption model for other developing countries, which couldn't have been achieved without strong political and government support. Success with Bt-brinjal has led Bangladesh to prioritize the field testing of a new late blight resistant potato (an important crop occupying ~0.5in Bangladesh) which was approved. All these successes in crop technology transfer projects are possible Public-Private Partnerships (PPP) mode. PPP is flexible projects that have been successful and arrived at the farmer level within a short period. Recently, four PPP projects had brought a tremendous escalation in genetic modified crop adoption, i.e., Bt-brinjal in Bangladesh, Herbicide tolerant soybean in Brazil, drought tolerant sugarcane in Indonesia and the WEMA project for drought tolerant in maize in selected countries of Africa.

6. Socio-Economic Appraisal of Genetically Modified Crops

On the adaption of GM crops, there was a lot of debate on implication of GM crops on nutrition, income, poverty and health concern, for which national and international policies towards GM crops are not friendly towards adaptation. The literature indicated that some of the developed countries have adapted GM technology with right policy with regulatory mechanism. This emerging technology is now in third generation to evolve nutrient efficient foods and also help to alleviate poverty among farmers as well as increase agricultural production sustainability. The comprehensive study between 1996 to 2021,to estimate country wise benefits due to GM crops, it was reported that both the developing and developed countries had equal economical profits during the first 25 years of commercialization of biotech crops. As per the report of Mathur *et al* [62], total global economic benefits were US$14 billion of which developing countries together generated about US$ 7.7 billion (55% of global benefits), whereas developed countries generated around US$ 6.3 billion (44% of global benefits) from GM crops, it indicates that the GM crops enhance revenues for developing countries. Some studies have analyzed welfare effects to consumers as well as producers on GM crops at macroeconomic perspectives [63,64]. Anderson [63] reported that the adoption of GM crops by the USA, Canada and Argentina would have benefited the world by almost US$ 2.3 billion per year, of which 1.3 billion is reaped in the adopting countries while Asia and EU benefited in the form of improvement of trade, as net importers of the farm products. Frisvold *et al* [65] reported that the total cotton production was increased by 0.7% in 2001 because of high cultivation of cotton in USA and China alone, thus the world cotton price decreased by US$ 0.31 per Kg. Net global economic effects were US$ 838 million worldwide with consumers benefitting US$63 million. Some of the studies have consistently confirmed 50% to 110% increase in profits with the adoption of Bt-cotton compared to conventional cotton, equivalent to a range of US$ 76 to US$ 250 per hectare [66]. Subramaniann and Qaim [67] highlighted the direct and indirect effects of Bt-cotton adoption in India on the basis of village modeling approach. They suggested that large farmers benefitted more than the small-scale farmers due to higher investments. Despite that, household incomes of small farmers cultivated Bt-cotton were increased by 134% compared to conventional cultivators. The adoption of Bt-cotton also increased employment especially to women farmers in cotton picking activities. Female farmer employment increased by 55% as compared to male employment with the adoption of Bt-cotton in India. It indicates the adoption of Bt-cotton will have significant influence on reducing poverty. Sawaya [68]also confirmed that the small farmers are gaining more due to adoption of Bt-corn in the Philippines. These cross-country studies suggest that Bt- technology could be a pro-poor technology to increase yields, profits and reduce risk among small farmers in most countries.

7. Regulatory Issues of Genetically Modified Crops

Genetic modified foods do not differ in nutrition or cause any detectable toxic effects in animals [69]. It is the prime work of the government to ensure that novel foods are safe for human consumption and that novel long-term agricultural inputs do not cause major harmful impacts on the environment. These potential undesirable environmental and/or human health consequences arising from the introduction of GM plants led to the development of specific regulatory regimes to assess safety issues [70]. New laws and institutions emerged to regulate the prospective biosafety and food safety issues that required to be approved for GM products before they may be grown in, consumed in or imported into a country [25]. Another reason for the lack of GM crop approvals in some countries is often due to public rejection and financial capital constraints. So, it is extremely important that research programs, field trials and commercial activities involving GM crops should be monitored right from the time of initiation for assessment of risks and incorporation of required management measures as per the regulations in the country [71,72]. With the advancement of genome editing, a new generation of gene-edited crops do not have the regulatory mechanism. A large number of traits have been produced using the designed nucleases in laboratory conditions whose field evaluation is yet to be done.

The origins of the biosafety protocol occurred at the UN Convention on Biological Diversity in 1992, which was signed by over 150 governments at the Rio "Earth Summit" and which came into force in December 1993. In the Convention on Biological Diversity (CBD), it was accredited that release of GM organisms (referred to in the CBD as 'living modified organisms' or LMOs) could have adverse effects on the conservation and sustainable use of biological diversity. So, the CBD negotiated and proposed the first international regulatory framework for safe transfer, handling and use of LMOs as ‘Cartagena Protocol on Biosafety’, which was adopted on 29th January 2000. This protocol had been signed by 103 countries (except the USA). So far, forty-three countries have ratified the protocol.

After a long appraisal, Genetic Engineering Appraisal Committee (GEAC) gave permission to an Indian seed company, Mahyco, to begin commercial production and sale of three varieties of Monsanto’s Bt-cotton seeds, thus offering Indian farmers a new tactic for protection against bollworm in 2002. Cotton being an important fiber crop of India, its production suffered huge losses due to its susceptibility to insect pests prior to Bt-cotton introduction. India till now sustains its biotech cotton hectare and becomes the number one cotton producer in the world.

8. Conclusion and Future Prospects

Most of the genetic modified crops released for commercial production around the world are developed through transgenic modification. These crops have demonstrated that they are safe and nutritious as compared to their conventional counterparts. GM foods have both optimistic and pessimistic effects on organisms that feed on or interact with the crops or wider effects on food chains produced by increase or decrease in the numbers of other organisms. Still, they have the potential to solve many of the world's hunger and malnutrition problems and also help to protect and safeguard the environment by increasing yield and reducing reliance upon chemical pesticides and herbicides. Yet, the government has to face many challenges ahead of it, especially in the areas of safety testing, regulation, international policy, and food labeling. But we shouldn’t ignore a technology that has such enormous potential benefits. GM foods have essential role in world food security and to help in protecting the environment.GM foods are a logical way of feeding and medicating an overpopulated world. So, we must proceed with cautiously to avoid any unintended harm to human health and the environment and society. GM crops are an explicit mean to boost food production, without extension of land under cultivation. It is crucial to attain knowledge about all aspects of biotech crops, so that accurate decision without any prejudice thought could be made about crop biotechnology. Necessary steps need to be taken by academia and industry to educate people regarding the technology and its benefits so that they can make informed decisions about their food choices. In this direction, in June 2016, 123 Nobel Laureates signed an open letter emphasizing efficacy and safety of GM crops to the leaders of Greenpeace, the United Nations, and governments around the world. In the letter, they asserted that crops and foods developed through modern biotechnology are safe to use. Hence, the scientific evidence suggests that by adopting appropriate policy and regulatory frameworks GM crops will ensure a broader food security strategy.

With the advancement of genome editing, a new generation of gene-edited crops is being developed. A large number of traits have been produced using the designed nucleases in laboratory conditions whose field evaluation is yet to be done. Since the technology is used to edit endogenous genes to confer the desired traits, the crops developed through this technique may not be regulated like traditional GM crops. The success of new breeding techniques will only be possible by collective effort of scientific studies and social acceptance.

Compliance with ethical standards

Acknowledgments

The authors wish to acknowledge to the status report of genetic modified crops (http://www.isaaa.org/gmapprovaldatabase/default.asp.)

Disclosure of conflict of interest

There is no conflict of interest.

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