Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(1): 2405-2410
Received: 19-11-2017
Accepted: 20-12-2017

Genetically modified crops: An overview

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Abstract

Global demand for food is increasing with the growing world population and decreasing arable land. Food and agricultural systems have to respond to several changes with increasing international competition, globalization and rising consumer demands for improved food quality, safety, health enhancement and convenience. Modern biotechnology involving the use of RDNA technology/genetic engineering emerged as a powerful tool for improving the quantity and quality of food supply. Available worldwide with aim of enhancing productivity, decreasing the use of certain agricultural chemicals, modifying the inherent properties of crops, improving the nutritional value or even increasing shelf life. Concerns about the potential risks associated with their impact to human health, environment and biological diversity.

Keywords: genetic engineering, shelf life, anti sense, manipulation, *Bacillus thuringiensis* (Bt)

Introduction

Genetically modified crops (GMCs, GM crops, or biotech crops) are plants used in agriculture, the DNA of which has been modified using genetic engineering techniques. Genetic engineering is the simple addition, deletion, or manipulation of a single trait in an organism to create a desired change. In most cases, the aim is to introduce a new trait to the plant which does not occur naturally in the species.

History

10,000 years ago humans began domestication using selective breeding. During 1700s farmers and scientists started cross breeding plants. In 1980s researchers develop the more precise and controllable methods of genetic engineering to create plants with desirable traits. The first genetically modified crop plant was produced in 1982, an antibiotic resistant tobacco plant.

- The first GM crop was produced in 1982, an antibiotic resistant tobacco plant.
- The first field trials occurred in France and the USA in 1986, when tobacco plants were engineered for herbicide resistance.
- In 1987, Plant Genetic Systems (Ghent, Belgium), founded by Marc Van Montagu and Jeff Schell, was the first company to genetically engineer insect resistant (tobacco) plants by incorporating genes that produced insecticidal proteins from *Bacillus thuringiensis (Bt).*
- The first genetically modified crop approved for sale in the U.S., in 1994, was the *FlavrSavr* tomato.
- In 1994, the EU approved tobacco engineered to be resistant to the herbicide bromoxynil, making it the first commercial GM crop marketed in Europe.
- In 1995, Bt maize (CibaGeigy), bromoxynil resistant cotton (Calgene), Bt cotton (Monsanto), glyphosate resistant soybeans (Monsanto), virus resistant squash (Asgrow), and additional delayed ripening tomatoes (DNAP, Zeneca/Peto, and Monsanto) were approved.
- In 2000, Vitamin A enriched golden rice was developed.
- In 2013, the leaders of the three research teams that first applied genetic engineering to crops, Robert Fraley, Marc Van Montagu and MaryDell Chilton were awarded the World Food Prize for improving the "quality, quantity or availability" of food in the world.

Area and Production

In 2013, GM crops were planted in 27 countries; 19 were developing countries and 8 were developed countries. 18 million farmers grew GM crops; around 90% were smallholding farmers in developing countries. Between 1996 and 2015, the total surface area of land cultivated with GM crops increased by a factor of 100, from 17,000 km^2 (4.2 million acres) to 1,797,000 km^2 (444 million acres). 10% of the world's arable land was planted with GM crops in 2010. In the US, by 2014, 94% of the planted area of soybeans, 96% of cotton and 93% of corn were genetically modified varieties.

Use of GM crops expanded rapidly in developing countries, with about 18 million farmers growing 54% of worldwide GM crops by 2013. A 2014 meta analysis concluded that GM technology adoption had reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68% (Source: Clive James, 2014).

This reduction in pesticide use has been ecologically beneficial, but benefits may be reduced by overuse. Yield and profit gains are higher in developing countries than in developed countries.

Methods

Gene guns (Biolistics)

"Shoot" (direct high energy particles or radiations) target genes into plant cells. It is the most common method. DNA is bound to tiny particles of gold or tungsten which are subsequently shot into plant tissue or single plant cells under high pressure. The accelerated particles penetrate both the cell wall and membranes. The DNA separates from the metal and is integrated into plant DNA inside the nucleus.

This method has been applied successfully for many cultivated crops, especially monocots like wheat or maize, for which transformation using *Agrobacterium tumefaciens* has been less successful. The major disadvantage - serious damage can be done to the cellular tissue.

Agrobacterium tumefaciens mediated transfer

Agrobacteria are natural plant parasites, and their natural ability to transfer genes provides another engineering method. To create a suitable environment for themselves, these *Agrobacteria* insert their genes into plant hosts, resulting in a proliferation of modified plant cells near the soil level (crown gall). The genetic information for tumour growth is encoded on a mobile, circular DNA fragment (plasmid). When *Agrobacterium* infects a plant, it transfers this TDNA to a random site in the plant genome. When used in genetic engineering the bacterial TDNA is removed from the bacterial plasmid and replaced with the desired foreign gene.

The bacterium is a vector, enabling transportation of foreign genes into plants. This method works especially well for dicotyledonous plants like potatoes, tomatoes, and tobacco. *Agrobacteria* infection is less successful in crops like wheat and maize.

Clustered regulatory interspaced short palindromic repeats (CRISPR) (Gaj *et al.*, 2013) [9]

These are segments of prokaryotic DNA containing short, repetative base sequences. Each repitition is followed by short segments of spacer DNA from previous exposures to foreign DNA (virus or plasmid). Also called as cas system (CRISPR-associated system).

TALENS (Trascription activator- like effector nucleases) (Gaj *et al.*, 2013) [9]

These are artificial restriction enzymes generated by fusing TAL effector DNA- binding domain to a DNA cleavage domain. Restriction enzymes that cut DNA strands at a specific sequence.

Types of modification

When nucleic acid sequences are combined in a laboratory, the resulting DNA is called recombinant DNA. Plants made using genes found within the same species or a closely related one, where conventional plant breeding can occur is called "cisgenic" Transgenic plants have genes inserted into them that are derived from another species that could not naturally interbreed, is called "transgenic". Genetically modified plants can also be developed using gene knockdown or gene knockout to alter the genetic makeup of a plant without incorporating genes from other plants.

Traits

GM crops grown today, or under development, have been modified with various traits. These traits include improved shelf life, disease resistance, stress resistance, herbicide resistance, pest resistance, production of useful goods such as biofuel or drugs, and ability to absorb toxins and for use in bioremediation of pollution.

Genetic modification of vase-life in carnation

Florigene Ltd has developed transgenic carnation varieties. Produce flowers with an enhanced vase-life, as a result of alteration of either ethylene biosynthesis or ethylene perception. The flowers from the transgenic plants do not require chemical treatment for maximum vase-life (Chandler and Tanaka, 2007) [5].

Manipulation of senescence in Petunia

Flower senescence has been demonstrated to be readily manipulated in the pot-plant petunia. Senescence was the result of expression of a gene for biosynthesis of cytokinins (Chang *et al.*, 2003) [6], the overproduction or external application of cytokinin are known to delay senescence. Insertion of anti-sense ACC oxidase in transgenic petunia resulted in plants with flowers that had an extended vase- life (Aida *et al.*, 1998) [2] and keeping quality has been improved in begonia (Hvoslef-Eide *et al.*, 1995) [12].

Arctic apple (Waltz, 2015) [22]

In February 2015 Arctic Apples were approved by the USDA, becoming the first genetically modified apple approved for US sale. Gene silencing was used to reduce the expression of polyphenol oxidase (PPO), thus preventing enzymatic browning of the fruit after it has been sliced open. The trait was added to Granny Smith and Golden Delicious varieties. The trait includes a bacterial antibiotic resistance gene that provides resistance to the antibiotic kanamycin. The FDA approved the apples in March 2015.

Flavr savr tomato (Kramer and Redenbaugh, 1994) [14]

a) By expressing an antisense RNA complementary to the mRNA for an enzyme involved in ethylene production. These tomatoes make only 10% of the normal amount of the enzyme, thus delaying ethylene production
b) By blocking the polygalacturonase (PG) gene, which is involved in spoilage.
c) Plants were transformed with the anti-sense PG gene, which is mRNA that base pair with mRNA that the plant produces, essentially blocking the gene from translation.

Innate potato (Waltz, 2015) [22]

Developed by J R Simplot company. Designed to resist black spot brusing, browning and contains less of the amino acid asparagine that turns into acrylamide during the frying of potatoes. The innate name comes from the fact that this variety does not contain any genetic material from other species and RNA interference to switch off genes. The trait was added to the Russet Burbank, Ranger Russet and Atlantic varieties.

Colour: Suntory "blue" rose (Katsumoto *et al.*, 2007) [13]

After thirteen years of collaborative research, an Australian company – Florigene, and a Japanese company – Suntory, created a blue rose (actually lavender or mauve) in 2004. The genetic engineering involved three alterations – adding two genes, and interfering with another. One of the added genes was for the blue plant pigment. The roses are sold in Japan, the United States, and Canada.

Moon series carnations

Research has focused on the manipulation of either anthocyanins (red and blue colors) or carotenoids (yellow and orange colors), with the intent of creating a wider range of flower colors than occurs naturally, as well as to produce natural dyes for industrial purposes (Lu *et al.*, 2003). Florigene is selling Transgenic Moon series carnations engineered for dark violet- purple color around the world. The varieties are developed in Australia and flowers are produced primarily in South America for marketing in the United States and Japan.

Nutrition

- **Edible oils**

Some GM soybeans offer improved oil profiles for processing or healthier eating. *Camelina sativa* has been modified to produce plants that accumulate high levels of oils similar to fish oils.

- **Toxin reduction**

A genetically modified cassava under development offers lower cyanogen glucosides and enhanced protein and other nutrients (called BioCassava). In November 2014, the USDA approved a potato, developed by J.R. Simplot Company, that prevents bruising and produces less acrylamide when fried.

- **Vitamin enrichment**

Golden rice, developed by the International Rice Research Institute (IRRI), provides greater amounts of Vitamin A targeted at reducing Vitamin A deficiency. As of January 2016, golden rice has not yet been grown commercially in any country. Researchers vitamin enriched corn derived from South African white corn variety M37W, producing a 169 fold increase in Vitamin A, 6 fold increase in Vitamin C and doubled concentrations of folate. Modified Cavendish bananas express 10 fold the amount of Vitamin A as unmodified varieties

Golden rice (Potrykus, 2001) [18]

More than one third of the world's population relies on rice as a food staple, so rice is an attractive target for enhancement. Golden Rice was genetically engineered to produce high levels of beta-carotene, which is a precursor to vitamin A. Vitamin A is needed for proper eyesight. Other enhanced crops include iron-enriched rice and tomatoes with three times the normal amount of beta-carotene. Genes from daffodils and bacteria (*Erwinia carotovara*). Golden rice contains 37 mg/g of carotenoid, of which 84% is beta-carotene and also contains a gene for a bean iron storage protein, ferritin. The modified rice will provide vitamin A and iron.

Purple tomatoes (Butelli *et al.*, 2008) [4]

Enrichment of tomato fruit with health-promoting anthocyanins by expression of selected transcription factors. Expression of two genes from snapdragon that induce the production of anthocyanins in tomatoes, generates purple tomatoes. Anthocyanins offer protection against certain cancers, cardiovascular disease and age-related degenerative diseases.

Tearless onion (Thompson *et al.*, 2013)

By shutting down the lachrymatory factor synthase gene using RNAi technology, the conversion of valuable sulphur compounds to the tearing agent was inhibited.

Insect resistance: Bt maize (Bates *et al.*, 2005) [3]

Bacillus thuringiensis produces a bacterial toxin (Delta-endotoxin). The bacterium has been used as an insecticide since 1938. It stops the insect from feeding by attacking the insect gut lining.

European corn borer-resistant transgenic plants containing BT toxin developed by Mycogen. Transgenic Insect-resistant cotton (Monsanto) plants also contain BT toxin.

Trap crops

Biotechnology may offer unique opportunities for pest control in perennial tree and vine crops (Dandekar *et al*. 2002). Insects are attracted to the trap plant, but they multiply there and can spread to the adjacent crop. A variant on this concept is to incorporate expression of the *Bacillus thuringiensis (Bt)* insecticidal protein into the trap plant (root stock). When the insect feeds on the transgenic trap plant, it dies and the insect population is reduced, thereby protecting the nearby commercial crop.

Transgenic papaya (Gonsalves, 2004) [10]

The pivotal year in the history of Hawaii's papaya industry was 1992. In May 1992, papaya ring spot virus (PRSV) was discovered in Hawaii Island, where 95% of Hawaii's papaya was being grown (HASS, 2001) [11]. The timely commercialization of PRSV resistant transgenic papaya trees has revived Hawaii's papaya industry and provides an example of the challenges and opportunities for horticultural biotechnology. From the 1992 field trial, two cultivars were developed and designated 'SunUp' and 'Rainbow'. 'Sun- Up' is homozygous for the coat protein gene while 'Rainbow' is an Fl hybrid of 'SunUp' and the non transgenic 'Kapoho'.

Crown gall free apple

Biotechnology tool called "gene silencing" has been used to generate resistance to crown gall. This method involves transforming plants with DNA that, when expressed, produces signals that block the expression of any genes with the same sequence as the inserted DNA. Plants transformed with these interfering versions of the three enzyme genes would be primed to block the function of the corresponding bacterial genes in infected plants. This would prevent the formation of the damaging galls without even needing to kill the bacterium itself.

Roundup ready™ soybeans (Padgette *et al.*, 1996) [17]

A problem in agriculture is the reduced growth of crops imposed by the presence of unwanted weeds. Herbicides such as Roundup™ and Liberty Link™ are able to kill a wide range of weeds and have the advantage of breaking down easily. Development of herbicide resistant crops allows the elimination of surrounding weeds without harm to the crops.

Case studies

1. Recent Progress of Flower Colour Modification by Biotechnology (Tanaka *et al.*, 2009) [20]

Roses are the most important cut flower commercially wild roses usually have pink (these flowers contain anthocyanins derived from cyanidin) or white flowers. The cultivated roses we know today (*Rosa hybrida) are the product of extensive inter-specific hybridization utilising wild species including* yellow-flowered and orange-flowered species. However, despite the huge range of flower colours that have been bred, rose lack any varieties in the bluish range of flower colour because the genus *Rosa does not have the* biochemical pathway leading to delphinidin-based anthocyanins.

Key behind transgenics

The researchers then used RNA interference (RNAi) technology to depress all colour production by endogenous genes by blocking a crucial protein in color production, called dihydroflavonol 4-reductase (DFR) and adding a variant of that protein that would not be blocked by the RNAi but that would allow the delphinidin to work.

Expression of a F3'5'H gene from petunia, in rose resulted in no or little delphinidin accumulation in the petals of transgenic plants, even though these genes were shown to be functional in petunia, carnation or yeast. In contrast, expression of pansy (*Viola spp*) F3'5'H genes in rose resulted in a significant amount of delphinidin derived anthocyanins accumulating in petals. Rose cultivars that have higher vacuolar pH, large amount of flavonols (co-pigments) and weak or no F3'5'H activity were selected in order to enhance the blue hue of the transgenic petals and to achieve high content of delphinidin. Expression of pansy F3'5'H genes in such cultivars resulted in transgenic lines in which 95% of the anthocyanidins was delphinidin. The colour of the flowers in these lines was significantly bluer hue than any conventionally bred cultivar. In recent experiments, a torenia anthocyanin 5AT gene in addition to the pansy F3'5'H is identified. However, only a fraction of anthocyanins were modified and the acylation did not significantly affect the flower colour.

2. Genetically modified parthenocarpic eggplants: Improved fruit productivity under both greenhouse and open field cultivation (Acciarri *et al.*, 2002) [1]

Parthenocarpy, or fruit development in the absence of fertilization, has been genetically engineered in eggplant and in other horticultural species by using the *DefH9-iaaM* gene. The *DefH9-iaaM,* parthenocarpic gene is a biotechnological tool that enhances the agronomic value of all eggplant genotypes tested. Two greenhouse spring trials have shown that these plants out yielded the corresponding untransformed genotypes, while a summer trial has shown that improved fruit productivity in GM eggplants can also be achieved in open field cultivation.

Since the fruits were always seedless, the quality of GM eggplant fruits was improved as well. RT-PCR analysis demonstrated that the *DefH9-iaaM* gene is expressed during late stages of fruit development.

The main advantages of *DefH9-iaaM* eggplants are

1. Improved fruit productivity (at least 30–35%) under both greenhouse and open field cultivation;
2. Production of good quality (marketable) fruits during different types of cultivation;
3. Seedless fruit with improved quality. Such advantages have been achieved without the use of either male or female sterility genes.

Natural GMOs: The sweet potato (Kyndt *et al.*, 2015) [15]

When individuals oppose GMOs claiming that not natural since scientists are taking a gene from one species and adding it to another, it is often pointed out that horizontal gene transfer happens “naturally” without any human intervention. Sweet potato is one of the most important food crops for human consumption in the world. Because of the presence of this 'foreign' DNA, sweet potato can be seen as a 'natural GMO. The natural presence of *Agrobacterium* T-DNA in sweet potato and its stable inheritance during evolution is a beautiful example of the possibility of DNA exchange across species barriers. It demonstrates that genetic modification also happens in nature. In comparison to "natural" GMOs, that are beyond our control, human-made GMOs have the advantage that we know exactly which characteristic we add to the plant. It is not the first time that researchers find bacterial, fungal or viral DNA in the genome of plants or animals. High thorough genome analyses in recent years find more and more examples of possible "horizontal gene transfers". In a horizontal gene transfer there is exchange of genes between different species

Possible benefits of GM foods

1. Easing of world hunger
2. Development of crops that can be grown in marginal soil
3. Reduced strain on nonrenewable resources
4. Development of drought resistant crops
5. Development of salt-tolerant crops
6. Development of crops that make more efficient use of nitrogen and other nutrients
7. Reduced use of pesticides and herbicides
8. Development of pest resistant crops
9. Reduced herbicide use is better for the environment and reduces costs for farmers
10. Improved crop quality
11. Development of frost resistant crops
12. Development of disease resistant crops
13. Development of flood resistant crops
14. Improved nutritional quality
15. Development of foods designed to meet specific nutritional goals

Limits of GM foods (Sparrow, 2010) [19]

1. Allergic Reactions

According to research by the Brown University, resent genetically modified foods can pose significant allergy risks to people. It states that genetic modification often adds or mixes proteins that were not indigenous to the original animal or plant, which might cause new allergic reactions in our body. In some cases, proteins from organisms that you are allergic to might be added to organisms that you were not originally allergic to. This means your range of food choices will be lessened.

2. Not 100% Environmentally Friendly

Though it is claimed by many experts that genetically modified foods are safe for the environment, they actually still contain several kinds of substances that are not yet proven to be such. And what’s worse? These substances are remained hidden to the public.

3. Lower Level of Biodiversity

One big potential drawback of this technology is that some organisms in the ecosystem could be harmed, which in turn could lead to a lower level of biodiversity. When we remove a certain pest that is harmful to crops, we could also be removing a food source for a certain species. In addition, genetically modified crops could prove toxic to some organisms, which can lead to their reduced numbers or even extinction.

4. Decreased Antibiotic Efficacy

According to the Iowa State University, some genetically modified foods have antibiotic features that are built into them, making them resistant or immune to viruses or diseases or viruses. And when we eat them, these antibiotic markers will persist in our body and will render actual antibiotic medications less effective. The university also warns that ingestion of these foods and regular exposure to antibiotics may contribute to the reduced effectiveness of antibiotic drugs, as noticed in hospitals across the planet.

5. Unusual Taste

Genetically modified foods are observed to have unnatural tastes compared with the ordinary foods that are sold on the market. This could be the result of the substances that were added to their composition.

6. Not Totally Safe to Eat

It is proven by scientific studies that GMO foods contain substances that may cause diseases and even death to several kinds of species in this world, including us humans. For instance, mice and butterflies cannot survive with these foods.

7. Cross-Pollination

Cross-pollination can cover quite large distances, where new genes can be included in the offspring of organic, traditional plants or crops that are miles away. This can result in difficulty in distinguishing which crop fields are organic and which are not, posing a problem to the task of properly labeling non-GMO food products.

8. Gene Spilling

It is unclear what effects, if there are any, the genetic pollution resulting from inadequate sequestering of genetically modified crop populations would have on the wild varieties surrounding them. However, it is stressed that releasing pollen from genetically altered plants into the wild through the insects and the wind could have dramatic effects on the ecosystem, though there is yet long-term research to be done to gauge such impact.

9. Gene Transfer

Relevant to the previous disadvantage, a constant risk of genetically modified foods is that an organism's modified genes may escape into the wild. Experts warn that genes from commercial crops that are resistant to herbicides may cross into the wild weed population, thus creating super-weeds that have become impossible to kill. For genetically enhanced vegetation and animals, they may become super-organisms that can out-compete natural plants and animals, driving them into extinction.

10. Conflicts

GMO foods can cause a lot of issues in the merchants' daily life. How? These products might encourage authorities to implement higher tariffs to merchants, who would be selling them.

11. Exploitations

Some countries may use genetic engineering of foods as a very powerful weapon against their enemies. It is important to note that some scientists have discovered that these products can kill a lot of individuals in the world by using harmful diseases.

12. Widening Gap of Corporate Sizes

This disadvantage can possibly happen between food-producing giants and their smaller counterparts, causing a consolidation in the market. There would be fewer competitors, which could increase the risk of oligopolies and food price increases. Moreover, larger companies might have more political power and might be able to influence safety and health standards.

13. New Diseases

As previously mentioned, genetically modified foods can create new diseases. Considering that they are modified using viruses and bacteria, there is a fear that this will certainly happen. This threat to human health is a worrisome aspect that has received a great deal of debate.

14. Food Supply at Risk

GMO seeds are patented products and, in order to purchase them, customers have to sign certain agreements for use with the supplier or creator. As the reliance on these seeds expands around the world, concerns about food supply and safety also continue to arise. Furthermore, these seeds structurally identical, and if a problem affects one of them, a major crop failure can occur.

15. Economic Concerns

Bringing a genetically modified food to market can be a costly and lengthy process, and of course, agricultural bio-technology companies want to ensure a profitable ROI. So, many new plant genetic engineering technologies and products have been patented, and patent infringement is a big concern within the agribusiness. Also, consumer advocates are worried that this will raise seed prices to very high levels that third-world countries and small farmers cannot afford them, thus widening the gap between the rich and the poor.

Risk assessment

In general, the risks associated with transgenic crops are potential risks. However, research results provide emerging parameters to evaluate the relative magnitude of the potential risk. For example, good evidence is emerging that the combination of natural promiscuity regarding gene flow among crop varieties and engineered herbicide resistance is a serious concern. Likewise, it is becoming clearer that herbicide tolerant crops will probably not create 'superweeds' through crop-wild flow of genes that enable plants to tolerate particular herbicides. Rather weed problems will be enhanced by the selection of resistant weed populations through increased use of herbicides tied to particular transgenic crops, such as glyphosate-resistant soybeans. Research efforts should concentrate on the latter potential risks. Also of concern is the enhanced weediness of wild relatives of crops from the flow of genes enabling plants to resist insects and viruses. However, the research to evaluate the extent of these risks is incomplete (Sparrow, 2010) [19].

More study is needed to assess the potential for the widespread adoption by farmers of insect-resistant sunflower and virus-resistant squash to promote the development of wild plants with improved fitness relative to other wild plants. The improved fitness of particular plants in wild populations could alter plant and animal ecosystems. The controversy over the potential for Bt corn to harm monarch butterfly populations also illustrates the need to move beyond laboratory studies to comprehensive field scale when assessing the potential negative impact on susceptible but beneficial populations. That is, studies that account for the temporal and spatial interaction between the introduced technology and the organism of interest.

Conclusion

The commercial applications of GM to horticultural crops lag far behind those of agronomic crops. In some respects this is to be expected, since the majority of research and investment has been directed to commodities with the commercial value. For consumer and quality traits, however, many of the most interesting applications will be in horticultural crops (Clark *et al.*, 2004). However, the major impediment to horticultural biotechnology is the reluctance of the market to accept and actively promote these products. The development of products having compelling benefits for producers, marketers and consumers must be required to overcome this situation.

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