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Review Article

Transgenic plants: Types, benefits, public concerns and future

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ABSTRACT

The alteration of crops to improve their production was performed through the basis of selection before the creation of transgenics. This selection has been going on for thousands of years. By the year 2050, world population may reach nine billions. Food production will need to increase at the same rate or more in order to satisfy the needs of such an enormous number of people in some older centuries. So, there is a need to use the genetic techniques to improve crops over the recent decades. Through the use of transgenics, one can produce plants with desired traits and even increased yields. The transgenics would allow for more crops that last longer and withstand pests and diseases. Transgenic plant production will allow us to feed the growing population and to produce more desirable products. The future of GM crops remains a vital debate, as its applications have several advantages and disadvantages.

1. Introduction

Transgenic plants are the ones, whose DNA is modified using genetic engineering techniques. The aim is to introduce a new trait to the plant which does not occur naturally in the species. A transgenic plant contains a gene or genes that have been artificially inserted. The inserted gene sequence is known as the transgene, it may come from an unrelated plant or from a completely different species. The purpose of inserting a combination of genes in a plant, is to make it as useful and productive as possible. This process provides advantages like improving shelf life, higher yield, improved quality, pest resistance, tolerant to heat, cold and drought resistance, against a variety of biotic and abiotic stresses. Transgenic plants can also be produced in such a way that they express foreign proteins with industrial and pharmaceutical value. Plants made up of vaccines or antibodies (Plantibodies) are especially stricing as plants are free of human diseases, thus reducing screening costs for viruses and bacterial toxins.[1]

The first transgenic plants were reported in 1983. Since then, many recombinant proteins have been expressed in several important agronomic species of plants including tobacco, corn, tomato, potato, banana, alfalfa and canola.[2] Tobacco plants were generally used, however potatoes and bananas are also considered, for the purpose of vaccines for human beings.

2. Development of transgenic crops

Genetically engineered plants are generated in a laboratory by altering the genetic-make-up, usually by adding one or more

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genes of a plant's genome. The nucleus of the plant-cell is the target for the new transgenic DNA. Most genetically modified plants are generated by the biolistic method (Particle gun method) or by *Agrobacterium tumefaciens* mediated transformation method.

The "Gene Gun" method, also known as the "Micro-Projectile Bombardment" or "Biolistic" method is most commonly used in the species like corn and rice. In this method, DNA is bound to the tiny particles of Gold or Tungsten, which is subsequently shot into plant tissue or single plant cells, under high pressure using gun.[3] The accelerated particles are penetrating both into the cell wall and membranes. The DNA separates from the coated metal and it integrates into the plant genome inside the nucleus. This method has been applied successfully for many crops, especially monocots, like wheat or maize, for which transformation using *Agrobacterium tumefaciens* has been less successful.[4] This technique is clean and safe. The only disadvantage of this process is that serious damage can be happened to the cellular tissue.

The next method, used for the development of genetically engineered plants, is the "Agrobacterium" method (Fig. 1). It involves the use of soil-dwelling bacteria, known as *Agrobacterium tumefaciens*. It has the ability to infect plant cells with a piece of its DNA. The piece of DNA, that infects a plant, is integrated into a plant chromosome, through a tumor inducing plasmid (Ti plasmid). The Ti plasmid can control the plant's cellular machinery and use it to make many copies of its own bacterial DNA. The Ti plasmid is a large circular DNA particle that replicates independently of the bacterial chromosome.[3] The importance of this plasmid is that, it contains regions of transfer DNA (t DNA), where a researcher can insert a gene, which can be transferred to a plant cell through a process known as the "floral dip". A Floral Dip involves, dipping flowering plants, into a solution of Agrobacterium carrying the gene of interest, followed by the transgenic seeds, being collected directly from the plant.[3] This process is useful, in that, it is a natural method of transfer and therefore thought of as a more acceptable technique. In addition, "Agrobacterium" is capable of transferring large fragments of DNA very efficiently. One of the biggest limitations of Agrobacterium is that, not all important food crops can be infected by these bacteria.[3] This method works especially well for the dicotyledonous plants like potatoes, tomatoes and tobacco plants.

In research, tobacco and Arabidopsis thaliana are the most genetically modified plants, due to well developed transformation methods, easy propagation and well studied genomes.[5] They serve as model organisms for other plant species. Transgenic plants have also been used for bioremediation of contaminated soils. Mercury, selenium and organic pollutants, like as polychlorinated biphenyls (PCBs), have been removed from soils by transgenic plants, containing genes for bacterial enzymes.[6]

3. Types

Transgenic plants have genes inserted into them, deriving from other species. The inserted genes can come from species within the same kingdom (plant to plant) or between kingdoms (bacteria to plant). In many cases, the inserted DNA has to be modified slightly in order to correctly and efficiently express in the host organism. Transgenic plants are used to express proteins, like the cry toxins from Bacillus thuringiensis, herbicide resistant genes and antigens for vaccinations.[7]

Cisgenic plants are made up of using genes, found within the same species or a closely related one, where conventional plant breeding can occur. Some breeders and scientists argue that cisgenic modification is useful for plants that are difficult to crossbreed by conventional means (such as potatoes). Those plants in the cisgenic category should not require the same level of legal regulation as other genetically modified organisms.[8]

4. Advantages of transgenic plants

GM Technology has been used to produce a variety of crop plants to date. As the global population continues to expand, food remains a scare resource. Genetically engineered foods offer significant benefits by improving production yield,

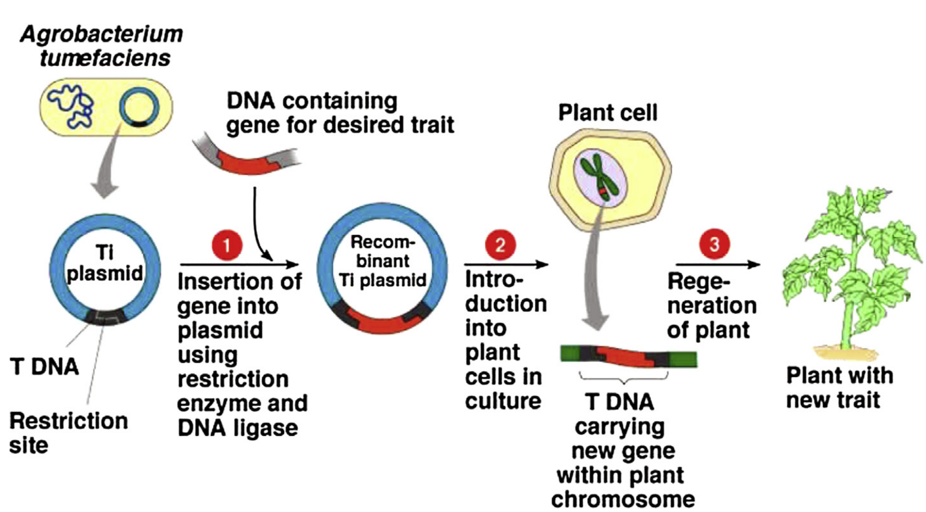

Fig. 1 – Agrobacterium mediated transformation.

lowering transportation costs and enhancing the nutritional content. Developments, resulting in commercially produced varieties in countries such as USA and Canada, have centerd on conferring resistance to insect, pests or viruses and producing tolerance to specific herbicides. While these traits had benefits for the farmers, it has been difficult for the consumers to see any benefit other than these. In limited cases, a decreased price owing to reduced cost and increased ease of production.[9,10] Several GM crops for malnutrition are expected to be revealed for cultivation in the coming five to ten years.[11]

5. Herbicide resistant plants

Plants that can tolerate herbicides are called Herbicide Resistant Plants. Glyphosate is an active ingredient of many broad spectrum herbicides. Glyphosate resistant transgenic tomato, potato, tobacco, cotton etc are developed by transferring aro A gene into a glyphosate EPSP synthetase from *Salmonella typhimurium* and *E. coli* Sulphonylurea resistant tobacco plants are produced by transforming the mutant ALS (acetolactate synthetase) gene from Arabidopsis. QB protein of photo system II from mutant Amaranthus hybrids is transferred into tobacco and other crops to produce atrazine resistant transgenic plants.

6. Insect resistant plants

Bacillus thuringiensis is a bacterium that is pathogenic for a number of insect pests. Its lethal effect is mediated by a protein toxin it produces. Through recombinant DNA methods, the toxin gene can be introduced directly into the genome of the plant, where it is expressed and provides protection against insect pests of the plant.

7. Virus resistant plants

TMV resistant tobacco and tomato plants are produced by introducing viral coat proteins. Other viral resistant transgenic plants are (a) Potato virus resistant potato plants (b) RSV resistant rice, (c) YMV resistant black gram and (d) YMV resistant green gram etc.

8. Pest resistant plants

There is clearly a benefit to farmers, if transgenic plants are developing a resistant into specific pest. For example, Papaya-ring-spot-virus resistant papaya has been commercialized and grown in Hawaii since 1996.[12] There may also be a benefit to the environment, if the use of pesticides is reduced. Transgenic crops, containing insect resistance genes from *Bacillus thuringiensis*, have made it possible to reduce significantly the amount of insecticide, applied on cotton in the USA. However, populations of pests and disease, causing organisms, adapt readily and become resistant to pesticides.

9. Nutritional benefits

Vitamin A deficiency causes half a million children to become partially or totally blind each year.[13–15] Milled rice is the staple food for a large fraction of the World's human population. Traditional breeding methods have been unsuccessful in producing crops, containing a high concentration of vitamin A. Researchers have introduced three genes into rice: two from daffodils and one from a microorganism. The transgenic rice exhibits an increased production of beta-carotene as a precursor to vitamin A and the seed is yellow in color.[16] Such yellow, or golden, rice may be a useful tool to treat the problem of vitamin A deficiency in young children living in the tropics.

10. Use of marginalized land

A vast landmass across the globe, both coastal as well as terrestrial has been marginalized because of excessive salinity and alkalinity. A salt tolerance gene from Mangroves (*Avicennia marina*) has been identified, cloned and transferred to other plants. The transgenic plants were found to be tolerant to higher concentrations of salt. The gut D gene from *Escherichia coli* has been used to generate salt tolerant transgenic maize plants. Such genes are a potential source for developing cropping systems for marginalized lands (MS Swaminathan, Personal Communication, 2000).

Researchers, at the University of California Davis campus have created transgenic tomatoes that grew well in saline soils. The transgene was a highly-expressed sodium/proton antiport pump which sequestered excess sodium in the vacuole of leaf cells. There was no sodium buildup in the fruit.

11. Reduced environmental impact

Water availability and efficient usage have become global issues. Soils subjected to extensive tillage (plowing) for controlling weeds and preparing seed beds are prone to erosion, and there is a serious loss of water content. Low tillage systems have been used for many years in traditional communities. There is a need to develop crops that thrive under such conditions, including the introduction of resistance to root diseases currently controlled by tillage and to herbicides which can be used as a substitute for tillage.[17]

12. Therapeutic proteins from transgenic plants

Proteins of therapeutic importance, like those used in the treatment, diagnosis of human diseases can be produced in plants, using recombinant DNA technology. Scaling-up of these transgenic plants to fields, results in industrial production of proteins. The area of research combining molecular Biotechnology and Agriculture is called Molecular farming or pharming. The proteins produced in transgenic plants for therapeutic use, are of three types – (i) antibodies, (b) proteins and (iii) vaccines. Antibodies directed against dental caries, rheumatoid arthritis, cholera, *E. coli* diarrhea, malaria, certain cancers, HIV, rhinovirus, influenza, hepatitis B virus and herpes simplex virus are known to be produced in transgenic plants. Vaccines against infectious diseases of the gastro intestinal tract have been produced in plants like potato and bananas.[18] The another appropriate target would be cereal grains. An anti cancer antibody has recently expressed in rice and wheat seed that recognizes cells of lung, breast and colon cancer and hence could be useful in both diagnosis and therapy in the future.[19]

13. Other benefits of transgenic plants

Important advantage of GM food is its enhanced ability to withstand long-distance transportation. The GM crops are picked, when still green are allowed to ripen during transportation, therefore yielding a longer shelf life. Even with prolonged shipping and storing periods, the product reaches its destination without spoiling.

According to the manufacturers of these GM crops, using these seeds will yield a number of benefits, including increased yields and decreased costs. They push GM crops as a second "Green Revolution" in a World, with billions of hungry mouths to feed.

14. Disadvantages of transgenic crops

The use of transgenic crops was an issue for many years. Many concerns have been raised and these are falling into two categories.

1. A concern, about what affect genetically modified material, could have on human health. For example, transgenic crops have been suggested to cause allergies in some people, although it is uncertain, whether transgenic crops are the source of this reaction.[20] Furthermore, the antibiotic resistance genes, placed in these crops have been suggested to cause resistance to antibiotics, leading to super bugs, which cannot be killed with antibiotic treatments.[21] The population being uncomfortable with ingesting DNA that originated from another source, like virus or bacteria.
2. A concern, about whether transgenic crops cause damage to the natural environment. One example that includes pollen from transgenic corn, which has capacity to kill the Monarch butterfly larvae. It has been shown that hybrid corn expresses a bacterial toxin in its pollen, which is then dispersed over 60 m by wind. In this range, the corn pollen is deposited on other plants near cornfields, where it can be ingested by non-target organisms including the monarch butterfly[21] which leads to their death.

The following are, however, potential issues of concern for plant protein production.

1. Allergic reactions to plant protein glycans and other plant antigens.
2. Plant and product contamination by mycotoxins, pesticides, herbicides and endogenous metabolites.
3. Regulatory uncertainty, particularly for proteins requiring approval for human drug use.[22]

15. Regulation of transgenic plants

In the United States the Coordinated framework for Regulation of Biotechnology governs the regulation of transgenic organisms, including plants. The Government's view, which we share, is that, this is impractical and that the methods recommended by the World Health Organization are adequate to ensure that any possibility of an adverse effect on human health from a GM food can be detected. The three Agencies involved in this are:

- ➢ USDA Animal and Plant Health Inspection Service who state that the Biotechnology Regulatory Services (BRS) program of the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is responsible for regulating the introduction (importation, interstate movement and field release) of Genetically engineered (GE) organisms that may pose a plant pest risk. APHIS protects Agriculture and the environment by ensuring that Biotechnology is developed and used in a safe manner. Through a strong regulatory framework, BRS ensures safe and confined introduction of new GE plants with significant safeguards, to prevent the accidental release of any GE material.
- ➢ EPA-Environmental Protection Agency—evaluates potential environmental impacts, especially for genes which produce pesticides.
- ➢ DHHS, FDA—Food and Drug Administration—evaluates human health risk, if the plant is intended for human consumption.

16. Should we use transgenic crops?

The perceived advantages and disadvantages of transgenic crops must be married to each other, to provide a crop that is environmentally sound and non-hazardous. Producers of transgenic crops and the agencies that study their effects are aware of this point. However, to date, there has been little evidence to support either case. More research is required in this field to determine the true safety of these plants and to decide, whether they are safe for both the environment and for those, who consume these products over the ages. At the least, most would agree that, the potential advantage of producing crops, which provide the human population with more and cheaper food, makes transgenic technology a useful invention.

17. The future

Although genetically modified crops offer a potential solution to food shortages around the globe, the viability of their cultivation remains questionable. The enhanced production of GM crops to eliminate hunger, carries hidden costs in environment and health concerns. The issue continues to be controversial and the future of genetically modified crops remains uncertain.

The commercial success of transgenic crops during 1994–2002 has demonstrated that significant benefits are going to accrue from the use of transgenic crops for commercial cultivation at farmer's field. Significant benefits will include the following: (i) improved and more efficient weed control; (ii) decreased losses due to insect pests and viruses and decreased need of insecticide; (iii) decrease in post-harvest losses due to better shelf life and marketing flexibility (tomato) due to resistance against storage pests; (iv) increase in nutritional quality (oil in canola); (v) more effective production of hybrid seed. The above will not only help in sustainable food security system, but also a safer environment, due to reduced use of insecticide and pesticide. This will require the seed industry to respond to this changing situation, by supplying seed of these superior crops to the farmers. The developing countries will have to develop mechanisms and commercialization of these transgenic crops.

In future, the transgenic crops will be used not only for improved agronomic traits, but also for traits involving food processing, pharmaceuticals (including edible vaccines) and specialty chemicals. Transgenic rubber tree has also been produced and will be used for a variety of purposes. Thus the future of transgenic crops is bright and optimistic. The market for these crops is expected to reach the level of 3 billion US dollars in 2000 and six billion US dollars in 2005. These goals will be achieved by sustained efforts, both in industrialized and developing countries. The public and farmers will have to respond to this changing scenario. The significant role will have to be played by public and private sectors to realize the benefits of these transgenic crops, which will be produced in large number in the present decade (2000–2010).

18. Conclusion

In the future, researchers hope to be able to provide vaccinations and medicines in GM foods, which can provide medications to people in developing countries more easily. Medications incorporated into food are easier to transport and store than conventional medicine. The advancements made with transgenic plants have and will continue to have a great impact on the lives of many. Transgenic plants offer a new approach to producing and administering human antibodies. The use of genetic engineering for the production of biopharmaceuticals like erythropoietin to treat anemia and insulin to treat diabetes are well known. Future generations of GM plants are intended to be suitable for harsh environments and for the Enhancement of Nutrient content, production of pharmaceutical agents and production of Bioenergy and Biofuels.

Conflicts of interest

All authors have none to declare.

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