TRANSGENIC PLANTS: ROLE IN AGRICULTURE- A REVIEW

Yogesh Bhagat* and Sarita Gund
Department of Biotechnology, College of Agriculture, Dharwad-580 001, India

Received: 20-01-2014 Accepted: 01-06-2014

ABSTRACT
Genetic modification of plants has been the basis for the betterment of crops in modern agriculture. Since prehistoric times, farmers have practiced seed selection that resulted in better crops and yields. Hybridization followed by selection has led to the evolution of a wide range of crops and varieties. The power of these practices was greatly enhanced in the 20th century with the application of science of genetics leading to modern hybrid varieties of food crops like maize, sorghum, pearl millet and high yielding inbred varieties in self pollinated crops like rice and wheat. Despite the spectacular success in agriculture growth and food production largely ushered by Green Revolution technologies, the sustainability of such production advance is threatened due to population increase, depletion of natural resources- land and water and destabilizing factors such as biotic and abiotic stresses. Amidst these challenges the only way to expand production is to develop and deploy technologies that enhance output per unit of the input. The recent developments in new biology collectively known as Biotechnology promise to not only enhance productivity further, but also to address a wider range of constraints to production both in high production environment and also in grey and fragile areas.

Keywords: Abiotic stress, Biotic stress, Disease resistance, GM crops, Insect resistance, Nutritional quality.

Plant biotechnology which includes genetic engineering through transfer of genes from unrelated plants and microorganisms (GM technology) has profound impact in agriculture and one of its most important applications has been the development of transgenic crops or more popularly known as genetically modified (GM) crops. Millions of hectares of GM crop varieties of soybean, cotton, canola, maize, are being grown annually. As on 2013, the global area under transgenic crops is about 175.2 million hectares, grown in 38 countries including USA, Argentina, Canada, Brazil, China and South Africa etc. In the developing world, GM crops have had largest impact in Argentina, Brazil, China and South Africa. India has recently approved the release of first GM crops of cotton for cultivation in farmers’ field.

Since the development of transgenic crops in the 1980s and their commercialization sometime in mid-1990s, the focus was on market-oriented traits in commercially important crops like soybean, cotton and canola. GM technologies have benefited farmers by reducing the cost on pesticides and on chemical weed control. No GM varieties of a major food grain crops like rice or wheat are currently grown anywhere. Nonetheless, the GM technology raises much hope to ensure sustainable food production in addition to combating malnutrition.

GM Technology: Genetic engineering is one of the components of biotechnology, which enables genes that carry instructions for a particular trait to be isolated and moved from one organism to another. A transgenic plant contains a gene or genes isolated from different source that has been artificially inserted instead of the plant acquiring them through pollination. The inserted gene, known as transgene, may come from any unrelated plant or from any taxon. Plant with transgene(s) is often called “Genetically modified plant” (GM Plant) or “Genetically engineered plant” (GEP). The uniqueness of GM technology lies in the fact that genes transfers are not limited by reproductive barriers.

*Corresponding author: bhagatyogesh2010@gmail.com, Agarkhar Research Institute, Pune, Maharashtra, India
The GM technology involves following steps:
1. Generation of DNA fragments, cloning into a “vector” or vehicle and creation of a suitable gene construct.
2. Transfer of the gene construct into plant cells/tissues through a process called “genetic transformation”.
3. Selection of transformed cell lines or seedling using a suitable marker system and regeneration of fertile plants from the transformed cells.
4. Molecular analysis of transformed plants for stable integration, expression and inheritance of transgene(s).

Method of gene transfer into plants: With the development of recombinant DNA technology or genetic engineering, we have now means to introduce “novel” genes from variety of sources into target crops. Methods of gene transfer include (1) Use of plant pathogenic bacterium – Agrobacterium tumefaciens as a vector, (2) DNA coated metal micro projectiles and (3) direct uptake of DNA by protoplasts of plant cells. The main advantage of rDNA technology is that unlike hybridization it facilitates transfer of specific well-characterized genes from source organism to the target crop variety. Tremendous progress has been made in application of GM technology in Agriculture in the past two decades.

Genetic engineering of crop plants for herbicide resistance: Engineering herbicide resistance of crop plants has been the most successful area of GM technology applications. Tolerance/ resistance to herbicides could be achieved either through altering the level and sensitivity of the target enzyme to the herbicide or introducing the gene that can detoxify the herbicide in the plant. Using such strategies herbicide resistance in different crops, particularly soybean, corn, cotton, rapeseed, mustard, rice, maize, sugarbeet and alfalfa has been developed (Rai and Prasanna, 2000). The specific herbicides for which tolerance has been engineered are phosphinothricin (Basta™, Herbiacem™), glyphosate (Roundup™), sulfonylurea (Glean™), Bromoxynil (Buctril™) and 2,4-dichlorophenoxy acetic acid (2,4-D).

Engineering crop varieties for biotic stresses: Biotic stresses caused by insects, fungal, bacterial and viral pathogens inflict heavy losses to crop productivity. Deployment of host plant resistance and chemical control through pesticide application are the ways to combat the losses. Adequate gene sources imparting resistance to certain pests and diseases may not always be available in the germplasm to breed for host plant resistance. Genetic engineering has a specific role in this regard when there is no satisfactory level of resistance either in the primary or secondary gene pools of crops for exploitation through plant breeding.

Insect/ pest resistance: Development of insect resistant transgenic crops is one of the demonstrated successes of genetic engineering in agriculture. Transgenic plants carrying the insecticide protein gene from Bacillus thuringiensis (Bt) has been proved to be the most successful example. Bt is a soil bacterium, which synthesizes crystalline protein during sporulation. These crystal proteins are solubilized in the highly alkaline midgut of the larvae to release protoxin that interferes with the osmotic equilibrium and cell lysis ultimately leading to insect paralysis and death. The first transgenic tobacco plants with Bt were produced in 1987 (Vaeck et al., 1987), and subsequently several crop plants including cotton, corn, potato, rice, tomato, eggplant, canola, soybean etc., have been developed with Bt genes. As of now, more than 30 plant species that also include peanut, alfalfa, apple, white clover, broccoli, grapes, pear and sugarcane have been transformed with Bt cry genes (Ranjekar et al., 2003). Aside Bt genes, vegetative insecticidal proteins (VIP), proteinase inhibitors, plant lectins, α-amylase inhibitors and insect chitinase genes have also been tried in various crop plants for production of transgenics against insect pests.

Disease resistance: Considerable yield loss in most of the agri-horticultural crops is accounted due to diseases caused by fungi, bacteria and viruses. In India, a recent survey by Grover and Gowthaman (2003) reports that fungal diseases are rated as the major or at least second most important stress that contribute to yield losses in major cereals, pulses, and oil seed crops. Breeding for resistant varieties and use of agrochemicals are some of the strategies being followed in controlling pathogens. However, frequent breakdown of resistance in varieties, evolution of new races of pathogens and residual effect of agrochemicals still pose serious challenge to crop protection. Transgenic lines that express antifungal, antibacterial proteins have been
successfully produced in several crop plants. Among the genes that encode defense response proteins, pathogenesis-related (PR) proteins, plant ribosome inactivating proteins (RIPs), lipid transfer proteins (LTPs), polygalacturonase inhibitor proteins (PGIPs), antiviral proteins etc., has been widely used for developing transgenic plants of many species.

Following the first report of introduction of bean chitinase gene into tobacco and Brassica against *Rhizoctonia solani* by Broglie et al. (1991), there have been several reports on transgenics developed with different PR proteins. The important crops where PR genes were introduced to develop transgenics against different fungal pathogens include, rice, tobacco, brassica, potato, tomato and wheat. Some secondary metabolites such as phytoalexins are believed to have a role in plant defense. Transgenic plants with phytoalexins developed in rice, tomato, barley and wheat were shown to increase resistance to different fungi. Resistance genes involved R-Avr interaction has been isolated from many crops and fungus-resistant transgenics are being produced by incorporating the R genes in susceptible plants within a genus or a family or even outside the family (Grover and Gowthaman, 2003). Virus resistant transgenics have been developed in a number of crops by introducing either viral coat protein (CP) or replicase gene encoding sequences. A large number of transgenics in cereals, fruit crops, vegetable crops and legumes are reported to be developed through coat protein mediated resistance (Dasgupta et al., 2003).

**Tolerance to abiotic stress:** Abiotic stresses, particularly drought, salinity and low temperature are the major constraints for increasing crop production. The phenotypic and physiological status of the plant under stress is determined by accumulation of sugars and other solutes and osmotic adjustments. The complex genetic mechanisms of these stresses are governed by polygenes. Several stress related genes are now cloned and transferred to different crop plants for obtaining transgenics resistant/ tolerant to drought, salinity and cold. Transcription factor genes such as abscisic acid induced protein (abi3), dehydration response element (dreb1A), soybean cold inducible factor (scof1); signal transduction component genes-superoxide dismutase ( sod), serine acetyl transferase (sat), glutathione reductase (gr); fatty acid metabolism genes-glycerol 3, phosphate acetyltransferase (gpat); heat shock genes (hsr101); osmolyte biosynthesis genes-choline dehydrogenase (beta), Choline oxidase A (codA), Trehalose-6-phosphate synthetase gene (TPS1), pyrroline carboxylase synthetase gene (p5cs), Pyruvate decarboxylase (pdc1), have been cloned and used for developing transgenic plants. Transgenics resistant/ tolerant to drought, salinity and cold are already developed in Arabidopsis, tobacco, alfalfa, tomato, rice etc.

**Nutritional enhancement through genetic engineering:** Plants provide almost all the essential vitamins, amino acids, minerals and several other micronutrients essential for human health. Unfortunately, for the majority of poor people in the developing countries foods with all the essential nutrients are inaccessible. Their dependency only on staple food like rice, wheat, which contains low levels of micronutrients, lead to malnutrition among the poor people. Improving nutritional quality of crop plants is set to become a growing area of application for GM crop breeding. Micronutrient enriched rice with iron (Goto et al., 1999), β-carotene (Ye et al., 2000) and lysine by genetic engineering is now reality. A well-known example is the development of a rice variety with an enriched vitamin A and iron content. It was developed by international working group to contribute to a better vitamin A supply for millions of people today suffering from deficiencies leading to different clinical dysfunctions mainly in children and pregnant women in the developing countries. The so-called “Golden Rice” is being tested for bioavailability of vitamin A and allergenicity etc. Improvement of nutritional status of some of our major crops is one of the thrust areas of transgenic research in India. To begin with, work on three major crops- rice, wheat, and potato has already begun. High yielding rice varieties grown in India will be either transformed with constructs that would code for high α-carotene or by back crossing these varieties to “Golden Rice” transgenics already developed in Switzerland and Germany. Improving iron content in rice grains will be another thrust area. Nutritionally enhanced transgenic Indian varieties of potato carrying the ama1 gene are already under advanced field trials. If found suitable, these will be released for cultivation (Sharma et al., 2003).
Indian scenario of GM crops: Crop biotechnology research in India is mostly done by government and public sector institutions under different departments/ministries. The Department of Biotechnology (DBT), Indian Council of Agricultural Research (ICAR) and Council of Scientific and Industrial Research (CSIR) are the major organizations that support biotechnology programmes. The DBT supports various activities of biotechnology in the country and a major portion of its budget-Rs. 2897 lakhs was allotted to Crop Biotechnology research alone during the IXth Plan period. These organizations have been supporting research projects on development and evaluation of transgenics with genes of agronomic importance. To bring researchers with experience in different areas of biology together to address defined goals, a number of multi-institutional projects have been launched (Sharma et al., 2003). Considerable progress has been made in developing transgenic crops resistant to biotic stresses including insect resistant, resistant to diseases caused by fungi, bacteria and viruses.

While the GM product development is the major goal of many research institutions across the country, the Government of India also acknowledges the importance of evaluation of GM crops for health and environmental safety. To address the general concerns of public on genetically modified organisms, the DBT in collaboration with other government departments has developed a three tier regulatory system for biosafety evaluation of GM products. It comprises the following:

- Institutional Biosafety Committee (IBSC) set up at each institution for monitoring institute level research in genetically modified organisms.
- Review Committee on Genetic Manipulation (RCGM), functioning at DBT to monitor ongoing research activities in GMOs. A monitoring and Evaluation Committee (MEC), comprising agricultural scientists, was constituted in 1998 by RCGM to monitor and supervise field trials permitted by the government.
- Genetic Engineering Approval Committee (GEAC) in the Ministry of Environment and Forestry with the involvement of DBT and ICAR has been set-up to authorize large scale trials and environmental release of genetically modified organisms (Ghosh and Ramanaiah, 2000).

Biosafety concerns: The idea of transferring a gene from an unrelated organism using recombinant DNA techniques inherently entails greater risks than traditional cross breeding raised many potential concerns. The weight of scientific evidence though leads to the conclusion that there is nothing to substantiate this view, the success and benefit to the society at large from GM technology would depend on the public acceptance of GM foods. It is therefore, important that all questions related to perceived environmental risks from GMOs as well as safety of GM foods are properly addressed through satisfactory science based answers. Biotechnology has had its share of detractors and activists who claim GMO’s are dangerous to health and environment. The myths that have emerged with the advent of this technology are:

- Emergence of new species that turn out to be super weeds
- Evolution of pests that resist chemicals and other forms of protection
- Harm to ecosystem through destruction of non-target species
- Threat to Biodiversity
- Resistance to antibiotics in humans through GM foods
- Benefit to producers but not to consumers
- Private sector monopoly of GM technology

First of all, it should be understood that no technology is with “zero risk”. Secondly, the greatest threat to bio-diversity is in expansion of agriculture land and any technology that can help stop this and minimize the chemical inputs will probably be that of GM. Further, a large proportion of developing world agriculture is in the hands of small-scale farmers and whose interest must be safeguarded. If the food need by the expanding population is to be met, sustainable practices in Agriculture must be introduced without attendant damage to environment or natural resources. The potential of transgenic crops as a means to enhance agricultural productivity has been accepted by several countries as evident from their extent of adoption worldwide barring those of European Union. Nevertheless, because of the revolutionary nature of creating novel plants the likely risk and uncertainty may be created as a result of new and unrelated DNA sequences inserted into target varieties. In addition, it is perceived that the use of antibiotic resistance gene as selectable marker
in the production of transgenic pose serious implications to human health especially when products from genetically modified plants enter the food chain.

These and many more doubts plague the mind of public at large. Therefore, if the potential of GM technology is to be realized, it has to be done in a responsible manner with proper testing and regulatory mechanisms. There is a pressing need for scientists, policy makers, NGO’s, extension workers and progressive farmers to come together on a common forum to discuss some of the concerns about environment safety, socioeconomic effects, ethical and also regulatory issues. Fortunately, India is one among the few countries to adopt biosafety guidelines, with the involvement of concerned ministries and agencies. Several public sector institutions and private companies are already involved in evaluation and development of strategies for deployment of tranagens in the country. In the years ahead GM technology has a greater stake in increasing food production, improve the efficiency of food production and reduce the environmental impact of agriculture.

**CONCLUSION**

In the field of agriculture several crop plants have been genetically modified to have resistance to insects (cotton, maize, potato, melons and vegetables) and others to have resistance to herbicides (cotton, maize, oilseed, rape seed, wheat and soybean) and yet others to viruses and fungal pathogens (rice and potato), quality of foods has been improved (sunflower and canola), essential vitamins and amino acids added (golden rice, iron rich rice and lysine rich maize), shelf life of fruits enhanced (tomato and straw berry). In addition to pest and herbicide resistance, other traits that confer drought and salt tolerance are being added to crop plants through this technology. Future advances offer the promise of an impressive array of new and useful products that will enhance yield, quality, provide better nutrition, deliver needed vaccines (edible vaccines), produce more desirable fats and oil, and extended shelf life of fruits and vegetables (tomato and straw berry). It should be emphasized that the advantage of the transgenic crops solely lies on the farmers side. The first waves of transgenic crops solely lies on the farmers side. The consumer hardly derived any direct benefit which is why public apathy for this technology. With the shift in beneficiary profile, the situation may soon change when next generation transgenic crops enter the market. The successful development of the nutritionally rich especially “golden rice” and iron-fortified rice would be crucial. It is expected that acceptability of these value added rice would ultimately pave way for easy introduction of other transgenic products in the market.

**REFERENCES**


