# Transgenic Technology and Its Impact on Crop Improvement for Global Food Security

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**Abstract**

Transgenic technology has emerged as one of the most important biotechnological tools in modern agriculture. It involves the transfer of desirable genes from one organism into another to improve agronomic traits such as yield potential, pest resistance, herbicide tolerance, nutritional quality and abiotic stress resistance. During the last three decades, genetically modified (GM) crops have shown considerable contribution toward sustainable agriculture and global food security. With increasing world population, decreasing arable land and changing climatic conditions, conventional breeding alone is not sufficient to meet future food demands. Therefore, transgenic technology provides an alternate and faster approach for crop improvement. This review article discusses the historical development, methods, applications, advantages, limitations and future prospects of transgenic technology in agriculture. The impact of GM crops on food security, farmer income and environmental sustainability is also highlighted. However, biosafety concerns, ethical issues and public acceptance remain major challanges in many countries. Overall, transgenic crops have huge potential in ensuring food availability and agricultural sustainability in future years. (Ramesh et al., 2004; James, 2015)

**Key words:** *Transgenic, Agrobacterium, Bt. Cotton, Gene editing, Pesticides resistance*

## Introduction

Agriculture is the backbone of human civilization and food production is directly linked with survival of mankind. The global population is expected to reach around 9.7 billion by 2050, creating enormous pressure on agricultural systems for enhanced food production. At the same time, climate change, water scarcity, soil degradation and emergence of new pests and diseases are reducing crop productivity in many parts of world. Traditional breeding methods have contributed significantly in crop improvement, but these techniques are time consuming and often limited by sexual incompatibility barriers. Therefore, modern biotechnology and transgenic technology became essential tools for crop development. (FAO, 2022)

Transgenic technology refers to the insertion of foreign genes into plant genome through recombinant DNA technology. The inserted gene is called transgene and the resulting organism is known as transgenic or genetically modified organism (GMO). The technology allows transfer of useful genes even between unrelated species, which is impossible by conventional breeding. (Bawa and Anilakumar, 2013)

The first genetically modified plant was developed in 1983 and since then several transgenic crops such as cotton, maize, soybean, canola and rice have been commercialized worldwide. Bt cotton and Bt maize are among the most successful examples of insect resistant transgenic crops. Similarly, herbicide tolerant soybean and canola have improved weed management and crop productivity. (James, 2015)

Transgenic technology has opened new opportunities in crop improvement by enhancing resistance against biotic and abiotic stresses, improving nutritional quality and reducing dependence on chemical pesticides. Despite several controversies regarding biosafety and environmental concerns, many scientists beleive that GM crops can play an important role in combating hunger and malnutrition. (Qaim and Kouser, 2013)

**Historical Development of Transgenic Technology**

The development of recombinant DNA technology during 1970s laid foundation for genetic engineering in plants. In 1983, scientists successfully produced first transgenic tobacco plant using *Agrobacterium tumefaciens*. This was considered a major breakthrough in agricultural biotechnology. (Bevan et al., 1983)

During 1994, the first commercially approved genetically modified crop known as Flavr Savr tomato was introduced in United States. The tomato showed delayed ripening and improved shelf life. Later, Bt cotton and herbicide tolerant soybean gained wide popularity due to economic benefits. (Bruening and Lyons, 2000)

By 2020, more than 190 million hectares of GM crops were cultivated globally in countries such as United States, Brazil, India, Argentina and Canada. Bt cotton became highly successful in India and significantly reduced pesticide application against bollworm infestation. (ISAAA, 2020)

Recent advances in molecular biology, genome sequencing and gene editing technologies like CRISPR-Cas9 further enhanced the precision and efficiency of crop genetic improvement. Although CRISPR is technically different from transgenic approach, both technologies are often integrated for advanced breeding programs. (Doudna and Charpentier, 2014)

**Methods of Transgenic Technology**

**1. Agrobacterium-mediated Gene Transfer**

This is the most commonly used method for introducing foreign genes into plants. *Agrobacterium tumefaciens* naturally transfers T-DNA into plant cells causing crown gall disease. Scientists modified this bacterium to deliver beneficial genes without causing disease symptoms. (Horsch et al., 1985)

Advantages of this method include:

- High transformation efficiency
- Stable gene integration
- Low copy number insertion

However, monocot plants like wheat and maize were initially difficult to transform using this technique.

**2. Particle Bombardment or Gene Gun Method**

In this method, DNA coated gold or tungsten particles are bombarded into plant cells at high velocity. The foreign DNA enters nucleus and integrates into genome. (Sanford et al., 1987)

This method is useful for cereals and monocot crops but may result in multiple gene insertions and unstable expression.

**3. Electroporation**

Electroporation involves use of electrical pulses to create temporary pores in cell membrane through which DNA enters plant cells. It is mainly used for protoplast

transformation.
(Fromm et al., 1986)

**4. CRISPR and Advanced Genetic Engineering**

Modern biotechnology has integrated gene editing with transgenic approaches. CRISPR-Cas systems allow precise editing of target genes responsible for disease susceptibility, drought tolerance and yield traits. (Jinek et al., 2012)

**Applications of Transgenic Technology in Crop Improvement**

**Insect Resistance**

One of the most successful applications of transgenic technology is development of insect resistant crops through insertion of Bt genes from *Bacillus thuringiensis*. Bt crops produce Cry proteins toxic to insect pests. (Shelton et al., 2002)

**Bt Cotton**

Bt cotton reduced bollworm damage and increased farmer profit in India and China. It also lowered pesticide usage significantly. (Qaim and Zilberman, 2003)

**Bt Maize**

Bt maize showed effective resistance against stem borers and corn rootworms. Yield losses due to insect damage decreased substantially. (Hellmich et al., 2008)

**Herbicide Tolerance**

Herbicide tolerant crops can survive application of broad-spectrum herbicides like glyphosate. This allows better weed management and reduced tillage practices. (Duke and Powles, 2008)

Examples include:

- Roundup Ready soybean
- Herbicide tolerant canola
- GM maize

These crops simplified weed control and improved crop productivity.

**Disease Resistance**

Transgenic crops resistant to viruses, bacteria and fungi have been developed successfully.

**Virus Resistance**

Papaya ringspot virus resistant papaya saved papaya industry in Hawaii through expression of viral coat protein gene. (Gonsalves, 1998)

**Fungal Resistance**

Genes encoding chitinase and glucanase enzymes improved fungal resistance in several crops.
(Grover and Gowthaman, 2003)

**Abiotic Stress Tolerance**

Climate change has increased frequency of drought, salinity and temperature stress. Scientists developed transgenic crops with enhanced tolerance against abiotic stresses.

**Drought Tolerance**

Genes involved in osmoprotectant synthesis and stress signaling pathways improved drought resistance in rice, wheat and maize. (Ashraf, 2010)

**Salinity Tolerance**

Overexpression of ion transporter genes improved salt tolerance in transgenic plants.
(Zhang and Blumwald, 2001)

**Nutritional Enhancement**

Transgenic technology also contributed toward biofortification of crops.

**Golden Rice**

Golden Rice contains beta-carotene precursor of Vitamin A and was developed to combat vitamin A deficiency in developing countries. (Potrykus, 2001)

**Iron-rich Rice and Zinc-rich Crops**

Scientists developed biofortified transgenic crops enriched with micronutrients to reduce malnutrition problems globally. (Bouis and Saltzman, 2017)

**Impact of Transgenic Technology on Global Food Security**

Food security means availability, accessibility and affordability of nutritious food for all people at all times. Transgenic technology contributes to food security through several mechanisms.

**Increased Crop Productivity**

GM crops generally provide higher yields due to reduced losses from pests, diseases and weeds. According to reports, transgenic crops contributed billions of dollars in additional farm income worldwide. (Brookes and Barfoot, 2020)

**Reduction in Pesticide Usage**

Bt crops reduced dependence on chemical insecticides which lowered environmental pollution and health risks to farmers. (Klumper and Qaim, 2014)

**Improved Farmer Income**

Adoption of Bt cotton in India resulted in increased farmer profit due to lower pesticide cost and higher yields. Small farmers particularly benefitted from this technology.
(Kouser and Qaim, 2011)

**Sustainable Agriculture**

Herbicide tolerant crops promoted conservation tillage which reduced soil erosion and improved soil moisture conservation. (Duke and Powles, 2008)

**Combating Malnutrition**

Biofortified transgenic crops help address hidden hunger caused by micronutrient deficiency. Golden Rice is considered an important example in reducing vitamin A deficiency among children. (Potrykus, 2001)

**Challenges and Concerns of Transgenic Technology**

Despite several benefits, transgenic crops also face criticism and controversies.

**Biosafety Concerns**

Some scientists fear that transgenes may spread into wild relatives causing ecological imbalance. There are also concerns regarding development of resistant insect populations. (Snow et al., 2005)

**Human Health Issues**

Although no major harmful effects have been scientifically confirmed, public concern regarding allergenicity and toxicity of GM foods still exist. Long-term studies are continuously being conducted. (Domingo and Bordonaba, 2011)

**Ethical and Socio-economic Issues**

Patent rights and corporate control over seeds have raised concerns among farmers and policy makers. Small farmers may become dependent on multinational companies for seed purchase every season. (Shiva, 2000)

**Public Acceptance**

Many European countries have strict regulations against GM crop cultivation due to consumer resistance. Public awareness and transparent risk assessment are essential for wider adoption. (Frewer et al., 2013)

**Future Prospects**

Future transgenic research is focusing on climate resilient crops, nitrogen use efficiency and improved photosynthetic efficiency. Integration of artificial intelligence, genomics and gene editing may revolutionize crop improvement in coming decades.

Scientists are also working on edible vaccines, pharmaceutical crops and enhanced carbon sequestration plants. New breeding techniques combined with transgenic approaches may help achieve sustainable agriculture goals. (Doudna and Charpentier, 2014)

Developing countries with food shortages can significantly benefit from advanced biotechnology if proper biosafety regulations and farmer education programs are implemented.

**Conclusion**

Transgenic technology has transformed modern agriculture by providing innovative solutions for crop improvement and food security. Insect resistant, herbicide tolerant, disease resistant and nutritionally enhanced crops have demonstrated significant benefits in terms of yield improvement, reduced pesticide usage and enhanced farmer income. Bt cotton, Golden Rice and virus-resistant papaya are remarkable examples showing practical utility of genetic engineering in agriculture.

However, concerns related to biosafety, ethics, environmental impact and public acceptance should not be ignored. Proper regulatory frameworks, scientific risk assessment and transparent communication are essential for sustainable utilization of transgenic crops. Although transgenic technology is not a complete solution to global hunger, it can certainly become an important component of integrated agricultural development strategies. Future advancements in biotechnology and molecular genetics are likely to further enhance the role of transgenic crops in ensuring global food security and sustainable agriculture. (Qaim, 2020)

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