Int.J.Curr.Res.Aca.Rev.2023; 11(10): 18-25

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 11 Number 10 (October-2023)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2023.1110.003

Transgenic Crops and their Implications

Afework Legesse*

Department of Crop Research, Jimma Agriculture Research Center, Jimma, Ethiopia

**Corresponding author*

Abstract

Transgenic crops, also known as genetically modified crops, have been a subject of extensive scientific research and public debate due to their potential impact on agriculture and the environment. This review paper aims to provide an overview of transgenic crops, including highlight on global status of transgenic crops production, benefits, risks, and ethical considerations. The implication of transgenic crops in terms of food security, productivity enhancement, environmental sustainability, and socio-economic impacts were also discussed. Despite the advantage offered by transgenic crops, it is crucial to address potential risks and ethical concerns associated with their use.

Article Info

Received: 12 August 2023
Accepted: 26 September 2023
Available Online: 20 October 2023

Keywords

Agriculture, human technology, plants, animals, cross-fertilization.

Introduction

Agriculture is a very old form of human technology. For millennia, farmers have relied on selective breeding and cross-fertilization to modify plants and animals and encourage desirable traits that improve food production and satisfy other human needs. The discovery of the molecular structure of deoxyribo nucleic acid (DNA) by Watson and Crick in the early 1950s (Watson and Crick, 1953) paved the way for modern biotechnology which focuses on gene manipulation to enhance the ability of specific organisms to perform tasks or produce substances for human benefit. In the United States the yields of major crops such as corn, wheat, and soybeans increased for most of the twentieth century as a result of conventional breeding and other technological changes.

Among the possible ways of raising productivity, genetic engineering (GE) has been promoted in recent years by the biotechnology industry as a revolutionary new way to produce crops with dramatically increased yields (Biotechnology Industry Organization, 2009; Fernandez-Cornejo and Caswell, 2006). For numerous thousand years farmers have been changing the genetic composition of the crops they cultivate.

Human selection for a number of characteristics such as faster growth, food textures, seed diversity or sweeter fruits has radically modified cultivated plants compared to their wild native species. Amazingly, many of our current crops were developed by trial and error by simple people without any scientific training on plant breeding (UNESCO, 2000).

Genetically Modified Organisms (GMO) is crops or animals in which the genetic material (DNA) has been altered in a way to introduce genes from another organism or species using modern molecular biology techniques. The technology is often called “genetic engineering” or “gene technology”. It allows selected individual genes to be transferred from one organism into another, including also the transfer between non-related species. This is done to provide new properties and characteristics to the recipient elements of the genes which are natural in the donor element (Bolívar Zapata, 2011).

The first transgenic plants took place in 1983, and tobacco was the first plant used for this method, achieving its resistance to antibiotics. Professor Marc Van Montagu produced tobacco plants that were resistant to kanamycin and to methotrexate in his laboratory in Belgium. Tomato was the second plant, acquiring also resistance to insects. Before these achievements, Trans genesis had been successful in microorganisms in 1973, and in 1982, the first transgenic rat was created, becoming the first animal of this type (UNESCO, 2000).

More than a billion acres of transgenic crop land has been planted worldwide, with over 50 trillion transgenic plants grown in the United States alone. In the United States, over half of the corn and cotton and three-quarters of soybean produced are transgenic for insect resistance, herbicide resistance, or both. Biotechnology has been the most rapidly adopted technology in the history of agriculture and continues to expand in much of the developed and developing world (John and Sons, 2008).

Scientific base of Genetically modified Crops

A genetically modified (GM) crop is a plant into which one or more genes have been artificially inserted instead of the plant acquiring them under natural conditions of cross -breeding or natural recombination. The inserted gene sequence, known as the transgene, may be from same species, a different species with in the same kingdom or even from a different kingdom (e.g. genetically modified Bt corn, which produces the natural insecticide, contains a gene from a bacterium).

The process of genetic transformation involves several distinct steps, namely identification of useful gene, the cloning of the gene into a suitable plasmid vector, delivery of the vector into plant cell (insertion and integration) followed by expression and inheritance of the foreign DNA encoding a polypeptide. A gene construct consists typically of three elements: 1) The promoter functions as an on/off switch for when and where the inserted/modified gene is active in the recipient plant; 2) The transgene encodes a specifically selected trait, 3) The terminator functions as a stop signal for transcribing the inserted/altered gene.

Several methods of production of genetically modified organisms (GMO) are known. The foreign gene that has been inserted into the cell of a microorganism, a plant or an animal is called a transgene. It is integrated into the genome of the recipients which are called transgenic. The transgenes are genes with known traits or mutated variants of known genes. In most cases also marker genes are used because of identification of transgenic organism.

The integration of transgene into the cell is carried out by different methods: (a) Transduction with the use of bacteriophages (b) Transgene injection using pronuclear microinjection (Wall, 2001); (c) Transfer using modified viruses and plasmids (d) Electroporation method by which higher permeability of cell membrane is achieved (Charu Verma *et al.*, 2011). Methods of gene insertion in plants can be achieved by direct gene transfer like microprojectile bombardment or through biological vectors like a disarmed Ti (tumour inducing)-plasmid of *A. tumefaciens* (Leena Tripathi, 2005). Methods of direct gene transfer are used especially for the transformation of plant species, which are recalcitrant and not susceptible to agroinfection.

The methods of DNA delivery into plant cells are fundamentally different from agroinfection since the foreign DNA is introduced through physical means and no biological carriers are involved. Therefore, these techniques are not limited to the constraints characteristic of *Agrobacterium*-mediated transformation. The direct gene transfer methods include microprojectile bombardment, liposome fusion, microin-jection, PEG-mediated DNA uptake and electroporation. Microprojectile bombardment is a process by which transforming DNA is coated onto metal microcarriers of tungsten or gold that is accelerated to high velocity either by a gunpowder device or through compressed gases.

DNA carried on the microprojectiles remains biologically active inside the cell and can be expressed transiently or by integration into the chromosomal DNA of the host resulting in stable transformation. Microprojectile bombardment has become one of the major techniques for the transformation of plant cells where the cell wall need not be considered as an obstacle (Hamilton *et al.*, 1992).

Plant transformation mediated by the soil plant pathogen*Agrobacterium tumefaciens* has become the most commonly used method for plant transformation. Compared to direct gene transfer methodologies, *Agrobacterium*- mediated trans-formation offers several advantages such as the possibility to transfer only one or few copies of DNA fragments carrying the genes of interest at higher efficiencies with lower cost and the transfer of very large DNA fragments with minimal rearrangement (Shibata and Liu, 2000).

Highlights on global status of genetically modified crops

More than a billion acres of transgenic crop land has been planted worldwide, with over 50 trillion transgenic plants grown in the United States alone. In the United States, over half of the corn and cotton and three-quarters of soybean produced are transgenic for insect resistance, herbicide resistance, or both. Biotechnology has been the most rapidly adopted technology in the history of agriculture and continues to expand in much of the developed and developing world.

Although the first commercial GM crops were planted in 1994 (tomato), 1996 was the first year in which a significant area [1.66 million hectares (ha)] of crops were planted containing GM traits. Since then there has been a dramatic increase in plantings, and by 2005/06, the global planted area reached approximately 87.2 million ha. Almost all of the global GM crop area derives from soybean, maize (corn), cotton, and canola.

In 2005, GM soybean accounted for the largest share (62%) of total GM crop cultivation, followed by maize (22%), cotton (11%), and canola (5%). In terms of the share of total global plantings to these four crops accounted for by GM crops, GM traits accounted for a majority of soybean grown (59%) in 2005 (i.e., non-GM soybean accounted for 41% of global soybean acreage in 2005).

For the other three main crops, the GM shares in 2005 of total crop production were 13% for maize, 27% for cotton, and 18% for canola (i.e., the majority of global plantings of these three crops continued to be non-GM in 2005). The trend in plantings of GM crops (by crop) from 1996 to 2005 is shown in Figure 1.2 (John *et al.*, 2008).

In 2014, the global area of biotech crops continued to increase for the 19th year at a sustained growth rate of 3 to 4% or 6.3 million hectares (~16 million acres), reaching 181.5 million hectares or 448 million acres (Figure 1). Biotech crops have set a precedent in that the biotech area has grown impressively every single year for the past 19 years, with a remarkable 100-fold increase since the commercialization began in 1996. Thus, biotech crops are considered as the fastest adopted crop technology in the history of modern agriculture.

In 2014, a total of 18 million farmers planted biotech crops in 28 countries, where in over 94.1% or greater than 16.9 million were small and resource-poor farmers from developing countries. The highest increase in any country, in absolute hectarage growth was US with 3 million hectares. In summary, during the period of 1996 to 2014, biotech crops have been successfully grown in accumulated hectarage of 1.78 billion hectares.

Distribution of biotech crops in industrial and developing countries

Figure 2 shows the relative area of biotech crops in industrial and developing countries from 1996-2014. In 2014, for the third time, more than half (53%) of the global biotech crop area of 181.5 million hectares, equivalent to 96.2 million hectares, was grown in 20 developing countries. Unlike 2013, year-to-year growth was higher in the industrial countries at 4.2 million hectares (5%) than in developing countries at 2.1 million hectares equivalent to a 2% growth; this was principally due to higher growth in the US (soybean) and Canada (canola) in 2014.

Thus, whereas year-to-year growth was significantly faster in industrial countries in 2014, developing countries maintained a larger share of global biotech crops at 53% compared with only 47% for industrial countries.

Progress of biotech crops in Africa

In Africa, the use of GMO technology and its product is still in its infancy. South Africa is the only African country that is commercially producing GM crops. However, Egypt is approaching commercialization of four GM crops; these are potatoes, squash, yellow and white maize, and cotton (James, 2010).

In South Africa, under the Genetically Modified Organisms Act of 1997, three transgenic crops – in sector herbicide resistant cotton, maize and soybean have been approved for commercialization (Department of Health undated). GM crop plantings are growing: in 2004 South Africa had 500 000 ha under GM crops (James, 2004) and growth continued in white maize used for food and yellow maize used for feed; soybean plantings increased from 35 per cent adoption rate in 2003 to 50 per cent in 2004, whilst *Bacillus thuringiensis* (Bt) cotton stabilized with about 85 percent of producers adopting it (James, 2004).

Debate continues over whether GMO crops could help the country out of years of serious food shortages and Ethiopia banned import of GMO food, saying it would undermine farmers who already have their own traditional ways of fighting pests and weed.

Benefits of transgenic crops

Enhanced pest and disease resistance

Transgenic crops can be engineered to express proteins toxic to certain pests, thus reducing the need for chemical pesticides. This has the potential to increase crop yield and reduce the environmental impact of pesticide use. Increasing crop resistance to insects and diseases and reducing weeds could help reduce crop losses and reduce dependence on costly fertilizers and herbicides, resulting in valuable savings for resource poor farmers (Bernsten, 2004). For example, the European corn borer destroys 7-20 percent of the world's annual maize harvest (Ives *et al.,* 2001). If Bt can successfully control the corn borer, maize yields in Africa could increase significantly (Ives *et al.,* 2001).

Improved tolerance to abiotic stresses

By introducing genes that confer tolerance to drought, salinity, or extreme temperatures, transgenic crops can thrive in challenging environments, ensuring staple food production under adverse conditions. Cold tolerance Unexpected frost can destroy sensitive seedlings.

An antifreeze gene from cold water fish has been introduced into plants such as tobacco and potato. With this antifreeze gene, these plants are able to tolerate cold temperatures that normally would kill unmodified seedlings (Transgenic Research, 1999).

Drought tolerance/salinity tolerance As the world population grows and more land is utilized for housing instead of food production, farmers will need to grow crops in locations previouslynsuited for plant cultivation. Creating 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 (Nature Biotechnology, Vol 19, 2001 and In Vitro Cellular & Developmental Biology Plant, Vol 36, 2000).

Increased nutritional Value

Genetic modification can be used to enhance the nutritional content of crops, such as the bio- fortification staple crops with essential vitamins and minerals, addressing micronutrient deficiencies in vulnerable populations. Genetically modified crops may be important from a developing country perspective because specific nutritional values can be added (UN Millennium Project, 2005b). One of the best known genetic enrichment food crops is vitamin A improved rice, also called "Golden Rice" (Beyer *et al.,* 2002). Insufficient vitamin A intake by children in developing countries is the leading cause of visual impairment and blindness; affecting over three million children in sub Saharan Africa (SSA) (Muir, 2003). Pregnant women with vitamin A deficiency (VAD) face an increased risk of mortality as well as high risk of mother-to-child HIV transmission. Thus, if effective, nutritionally enhanced "Golden Rice" could be one important tool for addressing the MDG 5 on maternal health. "Golden Rice" is genetically modified to produce beta-carotene, the precursor of vitamin A (Beyer *et al.,* 2002). For beta-carotene to be converted to vitamin A, it requires a functional digestive tract, adequate zinc, protein and fat stores, adequate energy, and protein and fat in the diet.

However, in populations that suffers from VAD, the overall dietary deficiencies act as barriers to the conversion (Gola, 2005). The question also arises as to whether this is the most cost-effective and sustainable way to address nutritional deficits.

Risk and Challenges of Transgenic crops

Environmental impact

The introduction of transgenes into crops may have unintended effects on non target organisms and ecosystems. The potential for gene flow and the development of herbicide resistant weed population are areas of concern that need further research. The introduction of a transgene into a recipient organism is not a precisely controlled process and can result in a variety of outcomes with regard to integration, expression and stability of the transgene in the host (FAO and WHO, 2003). The risks associated with modifying the genetic structure of crops are not well understood and there is little agreement on either the severity or likelihood of potential risks. This controversy emanates from a scientific dispute about how "stable" GM crops are. Several concerns can be identified.

Table.1 Global GM area by country, data from James, 2015

Country	Area (millions of hectares)	% of global GM hectares	Crops
USA	73.10	40.3%	Corn, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash
Brazil	42.20	23.3%	Soybean, corn, cotton
Argentina	24.30	13.4%	Soybean, corn, cotton
India	11.60	6.4%	Cotton
Canada	11.60	6.4%	Canola, corn, soybean, sugar beet
China	3.90	2.1%	Cotton, papaya
Paraguay	3.90	2.1%	Soybean, corn, cotton
South Africa	2.70	1.5%	Corn, soybean, cotton
Pakistan	2.85	1.6%	Cotton
Uruguay	1.64	0.9%	Soybean, corn

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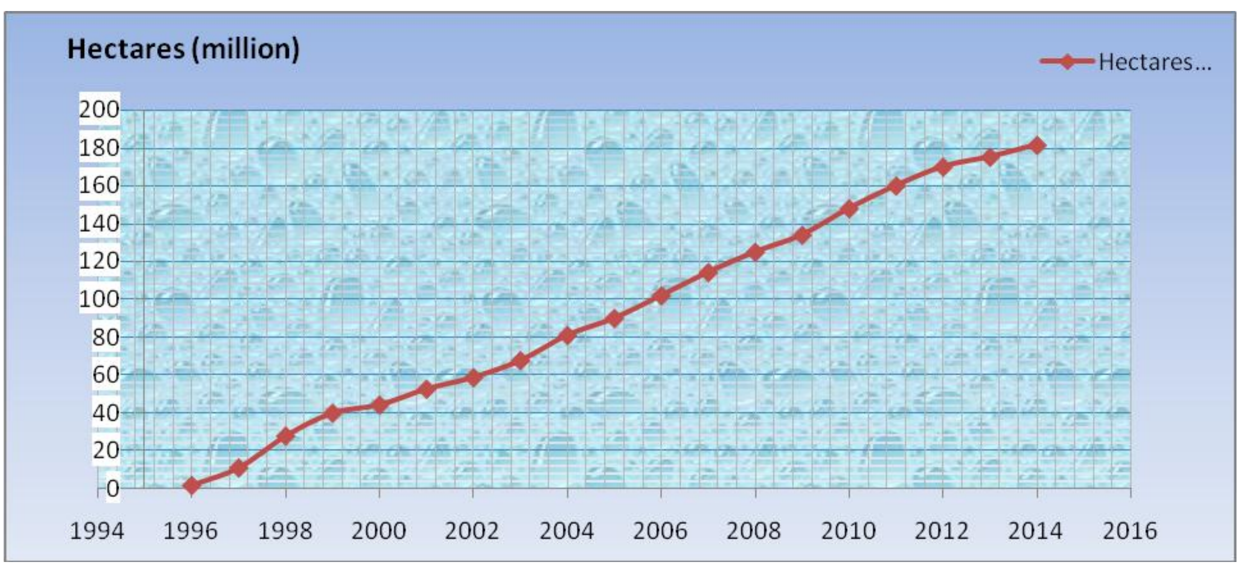
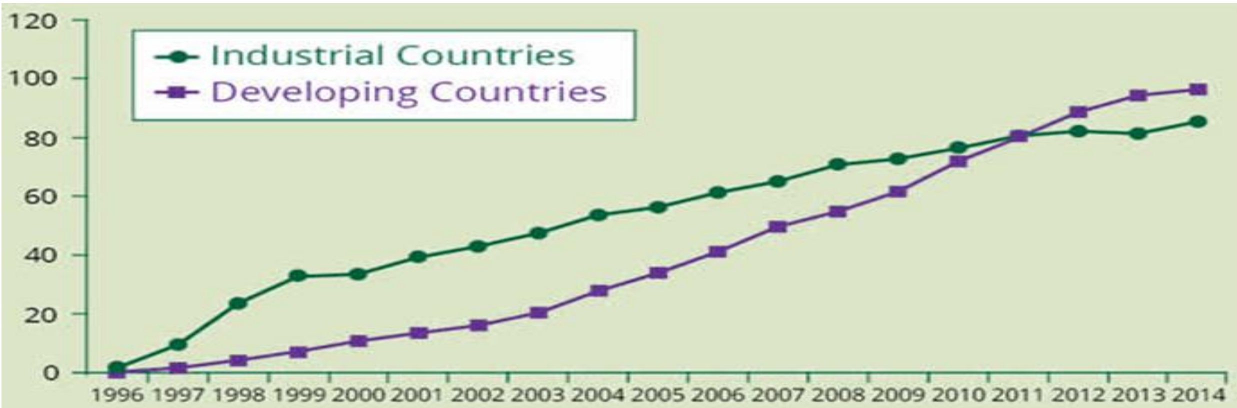
Argentina	24.30	13.4%	Soybean, corn, cotton
India	11.60	6.4%	Cotton
Canada	11.60	6.4%	Canola, corn, soybean, sugar beet
China	3.90	2.1%	Cotton, papaya
Paraguay	3.90	2.1%	Soybean, corn, cotton
South Africa	2.70	1.5%	Corn, soybean, cotton
Pakistan	2.85	1.6%	Cotton
Uruguay	1.64	0.9%	Soybean, corn

Fig.1 Global Area of Biotech Crops, 1993 to 2014 (million Hectares).



Source: Clive James, 2014.

Fig.2 Global Area of Biotech crops, 1996 to 2014: Industrial and developing Countries (Million hectares)



Source: Clive James, 2014

GM technology could result in the contamination of crops through gene transfer "genetic Pollution" and the development of "super weeds" (Altieri, 2002) and therefore have a negative impact on biodiversity. A further concern about GM crops is that the genes could "escape" and, through cross-pollination, mix with non-GM crops or their weedy relatives. For example, an herbicide tolerant gene could be transferred to weeds in wild habitats, turning them into "super weeds" (ERA, 2005). There is evidence of the unintentional spread of genes from GM crops (Monroe, 2004).

Transgenic crops modified to be resistant to a particular pest or disease may have a negative effect on non-target species that are harmless or beneficial. For example, Bt maize pollen may be toxic to the Monarch butterfly (Losey *et al.*, 1999).

Transgenic crops could encourage biodiversity loss through the establishment of monoculture agriculture which replaces traditional crops and other established varieties (Altieri, 2002).

Currently, the main potential cause of loss of biodiversity is agricultural expansion, which destroys habitats. The needs of a growing global population have largely been met by bringing more land into agricultural production (Ives *et al.*, 2001).

Ecological and health hazards are also posed by genetic use restriction technologies (GURT) which are commonly known as terminator technology (Mclean, 2005). These organisms do not flower and fruit and therefore provide no food for the multitude of insects, birds and mammals that feed on pollen, nectar, seed and fruit, and will inevitably have huge impacts on biodiversity (Mclean, 2005). Sterile trees can still spread by asexual means and the genes can spread horizontally to soil bacteria, fungi and other organisms in the extensive root system of the trees, with unpredictable impacts on the soil biota and fertility. As transgenic traits tend to be unstable, they could break down and revert to flower development, spreading transgenes to native trees, or creating pollen that poisons bees and other pollinators as well as causing potential harm to human beings (ISIS, 2005). The sterile monocultures are much more likely to succumb to disease, which could potentially wipe out entire plantations (Spinney, 1999).

Human health effects

The safety of consuming genetically modified crops remains topic of debate. Compressive studies are required to evaluate the potential long term health impacts of transgenic crops on human populations.

Increased use of herbicide-tolerant GM crops may pose new risks for environmental and human health. For example, glyphosate is a major formulation of "Roundup Ready" crops and is now the world's bestselling "total" herbicide. Due to the introduction of GMO-Roundup Ready crops, human and environmental exposure to the herbicide is expected to increase (Brown and Gow, 2005). However, there is strong evidence that glyphosate-containing products are acutely toxic to animals and humans (ISIS, 2005).

There are new medical risks from GM technologies. For example, gene therapy involves the use of a virus to carry a modified DNA segment and the virus is potentially pathogenic. The risks of these treatments are largely unknown. There are concerns that medical applications involving genetic engineering may produce cancer-causing genes from normal human genes (Portfolio 21, 2005).

The insertion of genes from one crop into another may increase allergic reactions, especially where consumers are not informed about the origins of the transgene. For example, soybean seeds genetically modified to include a gene from Brazil nuts in order to fortify a protein supplement containing soy resulted in people allergic to Brazil nuts reacting to the soy product (Mills, 2005). The modified soy product indicated no negative reactions when it was tested on animals, illustrating the difference between the reactions of laboratory animals and humans to GM food products. This warrants further study of this new technology before it is widely embraced. The soil bacterium *Bacillus thuringiensis*, from which endotoxin (Bt) genes are extracted and widely incorporated into GM crops as biopesticide, is a close relative of the anthrax bacterium, *Bacillus anthracis*, and exchanges genes with it. Potentially this can generate more deadly pathogens (Altieri, 2002; ISP, 2003). Some Bt genes are known to cause toxic or allergic reactions in humans (ISP, 2003). There is a growing concern that introducing foreign genes into food plants may have an unexpected and negative impact on human health. A recent article published in Lancet examined the effects of GM potatoes on the digestive tract in rats (Lancet, Oct 1999)

Gm crop may result in increased antibiotic resistance. For example, Novartis' Bt maize contains a marker gene, which codes for antibiotic resistance in *E.coli*. There is a risk that if animals or humans consume Bt maize-based products such as cattle feed or starch, some antibiotics would be rendered useless (Spinney, 1999). Vitamin toxicity from nutritionally enhanced crops may be an unintended consequence. When GM crops such as rice and rapeseed with high vitamin A concentrations are planted, there will be no way to distinguish them from normal crops, with the contingent risk of liver damage if too much vitamin A is consumed (Spinney, 1999).

Socio-economic issues

The adoptions of transgenic crops have socio-economic consequences, particularly for small scale farmers who may face dependency on a limited number of seed suppliers and potential loss of traditional varieties. Some companies have developed GM crop seeds that use GURT. As a result, farmers become dependent on large corporations and must purchase new seeds every season (ERA, 2005). In addition to social equity issues associated with these monopolistic tendencies, GURT may have environmental risks and thus the technologies require further evaluation. GM crops can be unstable (Hansen, 2000) posing risks to other plants.

Transgenic crops have the potential to contribute significantly to global food security; sustainability, and agricultural productivity. Food security is having sufficient physical, social and economic access to safe, nutritious and culturally acceptable food. The most promising technological option for increasing global food, feed and fiber production is to combine the best of the old and the best of the new by integrating the best of conventional technology (adapted germplasm) and the best of biotechnology applications, including molecular breeding and the incorporation of transgenic novel traits. However, there are legitimate concerns regarding transgenic crops potential risks and ethical implications. Establishing comprehensive assessment protocols, promising transparent practices, and fostering international collaborations are essential for harnessing the benefit of transgenic crops while addressing potential risks and ensuring ethical and responsible deployment.

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How to cite this article:

Afework Legesse. 2023. Transgenic Crops and their Implications. *Int.J.Curr.Res.Aca.Rev.* 11(10), 18-25.
doi: https://doi.org/10.20546/ijcrar.2023.1110.003