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Genetically Modified Crops

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Genetic engineering and plant transformation have played a pivotal role in crop improvement via introducing beneficial foreign gene(s) or silencing the expression of endogenous gene(s) in crop plants. Genetically modified crops possess one or more useful traits, such as, herbicide tolerance, insect resistance, abiotic stress tolerance, disease resistance, and nutritional improvement. To date, nearly 525 different transgenic events in 32 crops have been approved for cultivation in different parts of the world. The adoption of transgenic technology has been shown to increase crop yields, reduce pesticide and insecticide use, reduce CO_2 emissions, and decrease the cost of crop production. However, widespread adoption of transgenic crops carrying foreign genes faces roadblocks due to concerns of potential toxicity and allergenicity to human beings, potential environmental risks, such as chances of gene flow, adverse effects on non-target organisms, evolution of resistance in weeds and insects etc.

1. Introduction

Genetically modified (GM) crops are such crop plants whose genome is modified using genetic engineering techniques to improve the existing traits or for introduction of a new trait that does not occur naturally in the given crop species. The plants produced by the insertion of specific segments of foreign nucleic acid/gene sequence into its genome using transformation methods (such as Agrobacterium-mediated transformation or direct gene transfer) are known as transgenic plants (Griffiths *et al.*, 2005). The inserted gene, also known as transgene, may come from an unrelated plant, bacteria, virus, fungus, or an animal species. Thus, the advent of genetic transformation overcomes the major limitation of conventional plant breeding in which sexual compatibility between species is prerequisite to cross them.

In the year 1977, the natural ability of *Agrobacterium tumefaciens* to stably insert Ti plasmid DNA (T-DNA) into host plant cell genome was discovered (Chilton *et al.*, 1977), and hence, Ti plasmid was proposed as a vector to introduce foreign genes into plant cells. This study led the breakthrough related to development of transgenic plants. Subsequently, specific gene sequence was first reported to be transferred to plant cell using recombinant DNA and transformation technique (Herrera-Estrella *et al.*, 1983). The first transgenic plants, viz., antibiotic-resistant tobacco and petunia, were developed in the same year (Fraley *et al.*, 1983). In 1994, transgenic tomato, 'Flavr Savr' with the property of longer shelf life or delayed ripening developed by Calgene (Monsanto), was approved by Food and Drug Administration (FDA) for sale in the USA. Later on, several transgenic crops, such as canola with modified oil composition, Bt Potato, Bt maize, Bt cotton, bromoxynil herbicide-resistant cotton, and glyphosate-resistant soybeans, etc., received approval for commercialization.

2. Types of Genetically modified crops

2.1 Herbicide-tolerant transgenic crops: Weeds compete with crop plants for nutrients, water, sunlight and space, and hence lead to significant yield losses. Owing to crop yield loss by weeds, active management through various strategies such as use of herbicides is needed. However, because most weeds are herbaceous plants, selective killing of the weeds whilst protecting the crop plant is not always possible. Therefore, developing herbicide tolerance trait in the main crop is a potential solution which can facilitate flexible use of robust non-selective and broad-spectrum herbicides. The herbicides available for killing the weeds have two different modes of actions, selective or non-selective. Amongst the non-selective ones, glyphosate and glufosinate are the most extensively used herbicides. Notably, most of the herbicide-tolerant (HT) transgenic plants have been developed so as to tolerate glyphosate and glufosinate. Glyphosate specifically inhibits 5-enolpyruvyl shikimate3-phosphate synthase (EPSPS) enzyme, the key enzyme involved in the shikimate pathway of aromatic amino acid biosynthesis. As the shikimate pathway is not present in the animal kingdom, glyphosate is not harmful for human beings, birds, insects and other animals.

2.2 Insect-resistant transgenic crops: Insect pests and diseases cause severe crop loss. There are about 67,000 species of insects that cause losses to economically important crops. They damage crops by sucking sap or chewing plant parts like leaves, stems, and roots. Besides, insects also act as carriers of various plant pathogens which are transferred to plants at the time of feeding. For the control and management of insect pests, farmers rely on expensive chemically synthesised insecticides. This method of crop protection is not environment friendly and imparts economic burden on the farmers. Therefore, to overcome these drawbacks of insecticide use, newer technologies such as genetic modification of crops to enhance their resistance against insects have gained popularity. So far, ten insect-resistant transgenic crops have been commercialised for cultivation. Majority of these commercialised crops have been transformed with insecticidal genes (most commonly different variants of *cry* gene, and in a few events *vip* gene) which control the harmful insects attacking crops. Insect-resistant transgenic crops have the second largest area under cultivation—23.3 million hectares in 2017 (ISAAA 2017). The cry genes from soil bacteria *Bacillus thuringiensis* (Bt) are amongst the few highly exploited genes for developing insect-resistant transgenic crops. The *cry* genes produce Cry protein, which forms crystalline inclusions in bacterial spores. The Cry protein imparts insecticidal activities to *B. thuringiensis*. Cotton was the first commercially successful crop in which cry genes were incorporated to provide resistance against lepidopteron insect pest.

2.3 Abiotic stress-tolerant transgenic crops: A plethora of environmental factors referred to as abiotic stresses, such as drought, heat, cold, flooding, salinity, etc., exert a negative impact on growth and development of crop plants, leading to reduction in grain yield. With the ever-changing climatic conditions, the impact of these abiotic stresses is believed to be increasing. To cope up with abiotic stresses, plants alter their metabolism in many ways, such as by activating signalling cascades and regulatory proteins (for example, transcription factors and heat shock factors), activating/modifying antioxidant defence system to maintain cellular homeostasis, synthesising and accumulating compatible solutes (polyamines, sugars, betains, proline, etc.) which assist in osmotic adjustment, etc. These adaptive changes in plants in response to abiotic stresses, in turn, help in minimising the adverse effects on plants by maintaining the near-optimal conditions for plant growth and development. At the molecular level, abiotic stresses cause alterations in expression of an array of genes. Therefore, abiotic stress adaptation requires interplay of many gene networks. Due to complexity of the trait, lesser number of events conferring abiotic stress tolerance has been commercialised as compared to traits like herbicide, insect and disease resistance. To date, seven, three and two events pertaining to abiotic stress tolerance have been commercialised in maize, sugarcane and soybean, respectively (ISAAA database 2019).

2.4 Disease-resistant transgenic crops: Diseases caused by pathogens, such as nematodes, fungi, bacteria and viruses, cause extensive loss in the crop yield. Plant diseases are often managed through application of agrochemicals. However, the environmental hazards caused by the use of agrochemicals warrant exploration of alternative strategies to tackle plant diseases. Further, there are possibilities of development of chemical-resistant pests due to indiscriminate use of chemicals. To overcome the challenges posed by plant pathogens, it is important to develop inherent disease resistance in crop plants. This requires delineating the genes responsible for disease resistance and transferring the same to plants through breeding or biotechnological approaches. So far, 29 transgenic events pertaining to resistance to various diseases have been commercialised globally; of which, 25 events confer resistance against viruses. Most events for disease-resistance trait have been reported in potato (19 events) followed by four events in papaya, two events in squash and one event in bean, plum, sweet pepper and tomato each. Most of the virus-resistant transgenic crops have been developed via gene silencing techniques, such as co-suppression/RNAi and antisense RNA targeted against viral genes. Four different transgenic approaches that have been employed successfully for developing virus resistance are expressing viral coat protein (*cp*) gene to confer resistance through "pathogen-derived resistance" mechanism; expressing defective viral replicase and/or helicase domain to confer resistance through gene silencing mechanism; expressing sense and antisense RNA strands of viral replication protein (Rep); and use of antisense RNA to degrade mRNA coding for an important viral protein.

3. Concerns associated with the transgenic crops

The global adoption of transgenic crops in past two decades has delivered economic and environmental benefits in terms of increased crop yield, reduced chemical insecticide and herbicide applications, reduced CO_2 emission, increased farmer income and improved consumer health. However, some concerns have been raised about these crops being ecologically hazardous and potentially unsafe for human consumption. There are four principal concerns against transgenic crops, which are briefly discussed below.

3.1 Biosafety issues related to transgenic crops: Concerns have been expressed regarding the safety of transgenic food in terms of potential threat to human health (toxicity and allergenicity) and environment (possibility of transgene flow into environment and adverse effect on biodiversity). The issue of potential health risk of toxicity and allergenicity associated with transgenic crops has always been controversial. For instance, Cry9c expressing 'Starlink' maize has been approved for animal feed and industrial use in the USA in 1998 but is not approved for human consumption owing to its possibility for being allergenic to humans due to high stability of the protein (Bucchini and Goldman 2002) and the potential to interact with immune system. Later, this Lepidopteron insect-resistant maize named 'Starlink' was recalled worldwide by Aventis in 2000 owing to detection of residues of the Cry protein in food products (EPA 2017). However, direct link could not be established between Cry9c and allergic reactions in consumers.

3.2 Resistance breakdown: Extensive cultivation of transgenic IR and HT crops may increase chances of resistance development in the targeted insect population and weeds, respectively due to high selection pressure. The high selection pressure may potentially lead to evolution of new insect biotypes and can potentially result in the emergence of a superweed having resistance against the transgenic technology.

3.3 Adverse effects on non-target organisms: Potential unintended effects of transgenic crops on non-target organisms have also been explored in the article. For example, the higher mortality of monarch butterfly (*Danaus plexippus*) larvae fed on milkweed leaves dusted with the genetically modified Bt maize as compared to control under laboratory condition. Besides, reduction in monarch butterfly population has also been reported in Mexico and USA upon adoption of glyphosate-resistant transgenic crops. The decline in breeding habitat due to killing of milkweed plant by increased use of glyphosate was found to be the main reason for reduction in monarch butterfly population. Furthermore, shift in weed population, such as shatter cane, common water hemp, hemp sesbania, velvetleaf, nut edge and night shade, has also been reported due to continuous usage of glyphosate. It is possible that killing of the major pests may allow secondary pests to take over as major pest. For instance, it has been reported that wide-scale adoption of Bt cotton in China led to increase in population size of a previous minor pest, mirid bug, which in turn, acquired major pest status in past decade.

3.4 Cost for commercialization: One of the major limiting factors for development and deployment of transgenic crop products is the high cost of safety assessment and lengthy as well as complex regulatory approval process required for commercialization.

Conclusion

Considering the ever-increasing human population, shrinking arable land area and the rapid pace of climate change, there is a need to develop high-yielding crop varieties which are nutritionally enriched and tolerant to various environmental and biotic stresses. Transgenic technology has contributed towards development of crop varieties with enhanced yield, resistance to biotic and abiotic stresses, and enhanced food quality. Further, estimates also suggest that adoption of the transgenic technology has helped in reducing the use of pesticides and insecticides, decreasing environmental footprint and increasing farmer income. While these crops are granted regulatory approval only after strict food/feed safety assessment, such as allergenicity, toxicity and compositional analysis, etc., concerns have been raised regarding its safety to the environment and human health owing to potential risks related to gene flow, genetic drift, adverse effects on non-target organisms, evolution of resistant weeds and insects, and toxicity and allergenicity. Such potential environmental and human health implications of transgenic crops have contributed to their lesser consumer acceptance in many countries. To address some of the major concerns associated with transgenic crops, new alternative techniques, such as cis genesis, intra genesis and most recently, genome editing, are being used to develop improved crop plants.

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