Transgenic Plant Technology: An Insight into Insect Resistance

4

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Contents

Abstract

The production of the transgenic plant is an important tool in plant and agricultural biotechnology, which alters the plant genetic characters for improving the species-specific traits or for adding any novel or a beneficial trait that usually remains absent naturally in economical crops. The introduction of genetic

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transformation conquered the major constraint of conventional plant breeding. As a result, transgenic plant technology has been shown to enhance crop yield, reduce the use of insecticides and pesticides, and reduce crop production costs. Notably, crop yield loss due to insects is a leading threat to economic loss and food security worldwide. Insects cause two main classes of damage to growing crops—one is direct contact and the other is indirect damage through infection. One of the accomplishments of the transgenic plant has been the establishment and commercial cultivation of insect-resistant plants against different insect pests. This chapter sheds light on an important aspect of the different transgenic plants used in the development of insect resistance and their future impact on their ecological and economic perspectives.

Keywords

Transgenic plants · Insect pests · Resistance · Tolerance · Human health · Environmental safety

Learning Objectives

1. The introduction of genetic transformation conquered the major constraint of conventional plant breeding. Particularly, crop yield loss due to insects is a leading threat to economic loss and food security worldwide.
2. The production of the transgenic plant is an important tool in plant and agricultural biotechnology, which alters the plant genetic characters for improving the species-specific traits or for adding any novel or a beneficial trait that usually remains absent naturally in economically important crops.
3. Consequently, the development and deployment of transgenic plant technology have been revealed to enhance crop yields, decrease insecticide and pesticide usage, and reduce crop production costs.
4. This chapter provides an insight into the formulation of strategies of the different transgenic plants used in the development of insect resistance and their future impact on their ecological and economic prospects and in-hand societal awareness.

4.1 Introduction

The World population may cross the numbers 9 billion in recent times, there will be tremendous rise food of requirement in the future. To suffice the needs of such an enormous amount of food, crop productivity must increase at the same rate or even more with the increase in population. Agriculture is the most important socioeconomic practice in the entire world, and sustained agricultural growth is a necessity, not an option, for all the developing countries. Agriculture has always been the most important economic sector, which is strongly impacted by complex biotic stresses, like pathogens and insect pests. Insects are the most flourishing organism on the planet in terms of habitat and adaptation. Interestingly, insect pests have been a threat to crop cultivation ever since man has started growing crops. Severe losses in crop yields are caused due to the concerning blooms of insect pests. Among these, 9000 species are insects and mites, which are responsible for major yield losses in several of our important crops, particularly the tropical crops. As a result of the rigorous plant-pathogen interaction for several hundred million years, plants have developed some defense features against various insects as revealed by a plethora of key stress-inducible genes being identified, which are associated with defense response (Ferry et al. 2006; Lodhi et al. 2008; Srivastava et al. 2014, 2018; Ali et al. 2018; Pandey et al. 2019; Agarwal et al. 2020). However, these defense strategies remain insufficient to combat the major crop insect pests due to the experimental limitations involving these studies. One of the major problems in insect pest management using an insecticide is their broad-spectrum aspects, which makes them more vulnerable to kill several insect species including beneficial ones. This is itself a serious issue because we are losing the beneficial ones too, besides several other problems. Additionally, the development of insecticide resistance within 2–4 years of heavy use and the emergence of secondary insect pests due to loss of parasitoids and predators are other ancillary problems.

Applications of transgene technology in agriculture have clearly defined benefits, providing greater sustainability in terms of improved levels of crop protection, resulting in higher yields and reduced pesticide application (Tabashnik 2010). Some potential transgenic have been developed out of so many plant species against various insects. These transgenic plants are performing well in terms of pathogen resistance/tolerance as well as crop production (Babu et al. 2003). More resistance towards insects and diseases will allow plants to last longer and more crop productions. The need to feed the growing population with more desirable products will be solved by natural plant variety, breeding, or genome-edited plants (Rai et al. 2019; Dixit et al. 2020). Therefore, it is a primary requisite to use genetic modifications for the improvement of crops, which leads to a promising increase in yield, with desired traits and pest/pathogen tolerance. The concept of utilizing a transgenic approach to host plant resistance was realized in the mid-1990s with the commercial introduction of transgenic maize, potato, and cotton plants expressing genes encoding the insecticidal δ-endotoxin from *Bacillus thuringiensis*.

There has been an increase in the yield due to the introduction of insect resistance or tolerance in the transgenic crops. However, a major challenge in front of this new industry is the proper identification of suitable genes that are more specific to the target keeping in mind its benefits. In terms of insect resistance, several different classes of bacterial-, plant-, and animal-derived proteins have been reported to be insecticidal towards a wide range of economically important insect pests from different orders of the taxonomic hierarchy. With several advantages as well as disadvantages, the future of transgenic plant remains a subject of debate and examination for its future use and associated applications. There are two most important views for transgenic crop regulation (Dale 1995). In the first opinion, transgenic crops are improved versions of conventional crops and have been generated responsibly following the guidelines by researchers and plant breeders. The second point suggests that there is a need to develop more detailed and stringent regulations to govern genetic modification technology.

4.2 Transgenic Crops for Insect Pest Management: Advantages and Disadvantages

Insect tolerance in crops has been a key objective in agricultural and plant breeding applications. Almost billion dollars are spent on synthetic pesticides per year; for example, 15% and 23% of these insecticides are used to protect rice and cotton, respectively (Krattiger 1997). Pesticides worth billions of dollars are required annually for the production of economical crops, such as corn, tomato, wheat, cotton, or rice, to prevent different pathogens. However, pesticides have a significant role in the sustainable development of human society by increasing the quality and quantity of plant production. In contrast, unavoidable fears are also arising regarding their regular and continuously increasing use. The WHO's evaluation suggests that poisoning by pesticides causes 3 million cases per year, which further accounts for 250,000 deaths per year generally, because of unprofessional management and treatment (Stoytcheva 2011).

Application of insect-/pathogen-resistant crop varieties should be economically, environmentally, and ecologically beneficial. It is reported that the total cultivated area for genetically modified (GM) crops has reached 185.1 million ha till 2016 (Briefs 2016; Brookes and Barfoot 2017, 2018). GM crops mostly include crops such as corn, canola, rice, wheat, tomato, soybean, sugar beet, and cotton. These crops are mainly resistant to biotic stresses, such as insects, herbicides, and other abiotic stresses (Brookes and Barfoot 2017, 2018). For more than two decades, crops compassing toxin genes for insects have become commonly used in agriculture, which has brought about the reduction in pesticide application but also reduced the cost of production (Toenniessen et al. 2003; Gatehouse 2013). The first report on transgenic plants is comprised of gene encoding *Bacillus thuringiensis* (Bt) toxin that exhibited increased resistance to insect herbivores (Barton et al. 1987; Fischhoff et al. 1987; Vaeck et al. 1987; Gatehouse 2013). Reports suggest that a large reduction of insecticide usage occurred due to insect-resistant cotton (Naranjo 2009; Romeis et al. 2019). Due to the Bt cotton effectiveness, the utilization of synthetic insecticides has gone down (Bakhsh et al. 2009). It is also revealed that countries, such as Argentina, Mexico, India, China, and South Africa, lowered their insecticide practice by approximately 33–77% (Qaim 2009). After several studies encompassing the concepts of insect resistance, a series of effective researches on transgenic plants were recognized, the examples of which are listed in Table 4.1.

In addition to Bt genes, several additional genes of microorganisms, plants, and other origins depicting resistance for insect pests are used in crops (Table 4.1) (Kereša et al. 2008; Schuler et al. 1998; Gatehouse 2008). The proteinase inhibitors play a significant function in insect resistance and cause inhibitory activity in insect digestive enzymes. The genes for potato proteinase inhibitor II have been inserted in rice, cotton, and other economical crops (Gatehouse 2008; Duan et al. 1996). The

Table 4.1 Some genes used for the development of insect pest-resistant transgenic plants

Pathogen	Gene	Plants	Reference
BPH	*GNA*	Rice	Rao et al. (1998)
BPH	*ASAL*	Rice	Chandrasekhar et al. (2014)
Coleoptera	*cry3A(a)*	Potato	Adang et al. (1993), Perlak et al. (1993), Morán et al. (1998)
Coleoptera	*cry3A*	Alfalfa	Tohidfar et al. (2013)
Corn leaf aphid	*GNA*	Maize	Wang et al. (2005)
Cotton aphid	*ACA*	Cotton	Wu et al. (2006)
Cowpea aphid	*ASAL*	Chickpea	Chakraborti et al. (2009)
Grain aphid	*GNA*	Wheat	Stoger et al. (1999)
Jassid and whitefly	*ASAL*	Cotton	Vajhala et al. (2013)
Lepidoptera	*cryIA(b)*, *crylA(c)*	Cotton	Perlak et al. (1990)
Lepidoptera	*cryIA(b)*	Cotton	Tohidfar et al. (2005, 2008), Khan et al. (2011)
Lepidoptera	*crylA(c)*	Cotton	Bakhsh et al. (2012)
Lepidoptera	*cry1EC*	Cotton	Pushpa et al. (2013)
Lepidoptera	*cry1IA1*	Potato	Veale et al. (2012)
Lepidoptera	*cry1Ac9*	Potato	Davidson et al. (2004)
Lepidoptera	*Cowpea trypsin inhibitor*	Potato	Newell et al. (1995)
Lepidoptera	*cry1A(b)*	Soybean	Parrott et al. (1994), Dufourmantel et al. (2005)
Lepidoptera	*cry1A(c)*	Soybean	Dang and Wei (2007)
Lepidoptera	*cry1A(b)*	Rice	Fujimoto et al. (1993), Wünn et al. (1996)
Lepidoptera	*cry1A(b)*, *cry1A(c)*	Rice	Cheng et al. (1998)
Lepidoptera	*cry1A(c)*, *cry2A*	Rice	Bashir et al. (2005)
Lepidoptera	*cry1C*	Rice	Tang et al. (2006)
Lepidoptera	*sbk and sck*	Rice	Zhang et al. (2013)
Lepidoptera	*cry1A(b)*	Maize	Koziel et al. (1993)
Lepidoptera	*cry3Bb1*	Maize	Vaughn et al. (2005)
Lepidoptera	*cry3Bb1*, *cry34/35Ab1*	Maize	Gassmann et al. (2011)
Lepidoptera	*cry1A(c)*	Canola	Tabashnik et al. (1993), Stewart et al. (1996), Halfhill et al. (2001), Ramachandran et al. (1998)
Lepidoptera	*cry1A(c)*	Chickpea	Sanyal et al. (2005), Indurker et al. (2007)
Lepidoptera	*cry2A(a)*	Chickpea	Acharjee et al. (2010)
Lepidoptera	*cry1A(b)*, *cry1A(c)*	Chickpea	Mehrotra et al. (2011)
Lepidoptera	*cry1A(b)*	Tomato	Kumar and Kumar (2004), Koul et al. (2014)
Lepidoptera	*cry1A(c)*	Tomato	Mandaokar et al. (2000)
Mustard aphid	*ASAL*	Indian mustard	Dutta et al. (2005)

(continued)

Table 4.1 (continued)

Pathogen	Gene	Plants	Reference
Mustard aphid	*ASAL*	Indian mustard	Bala et al. (2013)
Mustard aphid	*ACA (Amaranthus caudatus agglutinin)*, *ACA-ASAL*	Indian mustard	Hossain et al. (2006)
Mustard aphid	*WGA-B*	Indian mustard	Kanrar et al. (2002)
Peach-potato aphid	*ConA*	Potato	Gatehouse et al. (1999)
Sap-sucking insects including BPH	*GNA*	Rice	Tang et al. (1999)
Sap-sucking insects including BPH	*DB1/G95A-mALS*	Rice	Yoshimura et al. (2012)
Sap-sucking insects including BPH and GLH	*GNA*	Rice	Foissac et al. (2000)
Sap-sucking insects including BPH and GLH	*GNA*	Rice	Nagadhara et al. (2003)
Sap-sucking insects including BPH and GLH	*ASAL*	Rice	Saha et al. (2006), Sengupta et al. (2010)
Sap-sucking insects including SBPH	*GNA*	Rice	Wu et al. (2002)
Sap-sucking insects including BPH, GLH, and WBPH	*GNA*	Rice	Ramesh et al. (2004)
Sap-sucking insects including BPH, GLH, and WBPH	*ASAL*	Rice	Yarasi et al. (2008)

BPH brown plant hopper, *WBPH* white-backed plant hopper, *SBPH* small brown plant hopper, *GLH* green leafhopper

lectins have also been effectively used against insect pests for crop protection (Goldstein and Hayes 1978). Several plant lectins have been shown to be lethal to various species of the orders Coleoptera, Diptera, and Lepidoptera (Czapla and Lang 1990; Eisemann et al. 1994).

It is gradually clear that consistent strong insect control approaches are required; the next generation of insect-resistant crops has the potential to accomplish this objective. Besides, the approaches (for instance, applying toxic proteins from other organisms, inhibitors, or lectins) of accomplishing insect resistance, plant-mediated RNAi machinery, and genome editing have emerged to fight insect infestations, particularly to address the development of resistance against the targeted insect pests (Rai et al. 2019; Tyagi et al. 2020; Price and Gatehouse 2008; Bisht et al. 2019). RNAi has a huge possibility to develop an effective method for insect pest management. The dsRNA comprising transgenic plants could be cost-effective due to the constant delivery of RNAi inducers throughout the whole plant life cycle. The knockdown of the specific gene has succeeded via orally served dsRNA in the different insect orders, such as Coleoptera, Diptera, Hymenoptera, and Lepidoptera (Terenius et al. 2011; Lynch and Desplan 2006; Dzitoyeva et al. 2001; Tomoyasu et al. 2008; Bakhsh et al. 2015). Accumulating studies suggest that many encouraging effects of plant-mediated RNAi technology have been used for knockdown of genes, such as cytochrome P_{450}, ecdysone receptor, and hunchback to give resistance or tolerance against insect infestations, like *Helicoverpa armigera*, *Spodoptera exigua*, and *Myzus persicae*, respectively (Mao and Zeng 2014; Mao et al. 2011; Zhu et al. 2012).

Genome editing in insects can be effectively used in different applications that interrupt chemical communication, chemical defense, and breeding companion identification (Tyagi et al. 2020). For instance, the olfactory receptor co-receptor gene knockout in *Spodoptera litura* by the CRISPR/Cas9 system leads to interruption in the breeding companion choice and impairment of insect infestation to host plants (Koutroumpa et al. 2016). The odorant receptor-16 gene knockout through CRISPR/Cas9-based techniques in *H. armigera* causes the males incapable of accepting pheromone signals from the mature females, thus succeeding in mating with undeveloped females that consequently headed to sterile eggs dumping, which is a very effective approach to control mating period for insect pest management in crops (Sun et al. 2017). The knockdown of the CYP6AE enzyme by CRISPR/Cas9 in the *H. armigera* verified the function in the purification of several toxic phytochemicals (Wang et al. 2018). Implementation of these technologies will be a probable choice to stop insect infestation in crops.

The use of transgenic crops has always been a subject of concern associated with human health and environmental safety. Due to some uncertain reasons, it has been found that some people are allergic to transgenic crops (Ferber 1999). Transgenic crops also comprise antibiotic resistance genes, which probably lead to superbug formation, and therefore, that microorganism becomes resistant to the particular antibiotic and eventually cannot be killed and hence the remnants are harmful to human society and other organisms (Losey et al. 1999). The natural environment also gets damaged by transgenic crops; for example, monarch butterfly larvae are being killed by transgenic corn pollen because it contains a bacterial toxin (Losey et al. 1999). Toxin containing corn pollen can be dispersed over 60 meters by wind flow and ingested by monarch butterfly, which is a nontarget organism and becomes dead. In this way, one of the beautiful examples of genetic polymorphisms as in the case of the monarch butterfly may face the challenges of negative evolutionary selection. Another reason for the disadvantage of the transgenic plant is the uncertainty in the authoritative regulation through government organizations, specifically for the approval of the use of specific proteins required for human drug use (Doran 2000; Shih and Doran 2009).

4.3 Limitations of Translation Regarding Transgenic Plants

Despite all the complications that GM crops have brought forth in many nations of the world, the use of transgenic technology to overcome insect pests has had a progressive impact on worldwide cultivation. While considering long-term effects, it is very challenging to take responsibility for the severe influences of transgenic plants on the surrounding environment. Transgenic plants in the field turn out to be the major component of several ecological pathways, like pollination and herbivory, hence affects insects and other plant species in various ways including the soil ecology after decomposition of the dead plant. Allergenicity, toxicity, and genetic hazards are three key threats to health that probably are associated with transgenic foods.

4.3.1 Impacts on Human Health and Animals

Allergens are not formed by genetic modification in any plant itself. If some gene is responsible for causing allergy and this gene is introduced in the plant, then only it can cause allergic reactions directly (e.g., by consuming the plant or its products) or indirectly (e.g., by inhaling pollens). Allergies for nuts are very common symptoms in human inhabitants. For example, Pioneer Hi-Bred developed a maize transgenic plant that causes allergy (Goodman et al. 2008). Another good example is transgenic soyabean plant containing a gene from Brazil nut induces the methionine level increase in the soybean increasing its nutrient value. As this transgenic soybean plant also caused an allergy, it became a serious concern against transgenic plant products. Nordlee et al. (1996) tested transgenic soybean and found that some people were allergic to nuts of the transgenic soybean and concluded that the Brazil nut gene responsible for increased nutritional value was accountable for producing allergic reactions. So, the transgenic plant regulation must be examined adequately to regulate the commercial use of transgenic plants (Nordlee et al. 1996).

Losey et al. (1999) reported that a monarch butterfly species showed harmful effects on its larvae due to the formation of insecticidal Bt toxin in the plant by entirely feeding on the pollen of Bt maize (Losey et al. 1999). Later on, many other studies established that the presence of Bt toxin in transgenic maize plant, which is consumed by monarch butterfly larvae, is sufficient enough to cause damage and mortality (Sears et al. 2001; Stanley-Horn et al. 2001). Carman et al. (2013) showed a significant increase in the weight of the uterus and severe stomach inflammation in transgenic maize plant feeding pigs. They took one herbicide-tolerant and two insect-resistant protein-coding transgenic maize plants as feeding material (Carman et al. 2013). Another study has been executed in poultry with Bt maize, and a significant difference between animals feeding on Bt maize and wild-type maize was observed. Czerwiński et al. (2015) also showed that two cultivars (Bacilla and PR39F56) of Bt maize feeding animals revealed an enlarged weight in the spleen, as well as a lower proportion of T-helper and T-cytotoxic cells in comparison with wild-type maize (Czerwiński et al. 2015).

4.3.2 Ecological Impacts

Transgenic plants, by sexual hybridization with related weeds, probably give rise to weeds that can be resistant to insect pests or herbicides due to acquired traits. These resistant weeds with acquired traits venture into the environment for ages and could compete with the transgenic plants or other crops for selective breeding. Insect pest and herbicide resistant weeds can take over massive space that can or be problematic for crop fields (Liang et al. 2018). The development of transgenic plants requires the introduction of antibiotic-resistant DNA into the genome. Although antibiotic-resistant DNA marker has no functional aspects outside the laboratory, still it is an integral part of plant genome and should be explored in future. It raises concerns about soil microorganisms, by acquiring antibiotic-resistant genes from transgenic plants through decomposition, leading towards the resistance of antibiotics in microbial organisms, consequently causing an alarming increase in antibiotic resistance levels in the natural environment (Tarafdar et al. 2014). With the growing cultivation of insect pest resistant/tolerant transgenic plants, the occurrence of nontargeted insect pests is highly increased that promises an alarming situation vis-à-vis ecological stability. As targeted insect pests could not depend on their preferred target plant, which has been genetically engineered, insects, therefore, can move to other plant species and this alteration, in turn, can affect the interruption of the regular flow of food chain in the ecosystem because this shift might bring new insect predators leading to an increase in competition for these genetically engineered plants (Bawa and Anilakumar 2013).

4.4 Horizontal Gene Transfer

Horizontal gene transfer (HGT) is the process of genetic material transfer to a living cell or organism, which is independent of sexual reproduction; however, it is expressed only after it enters into the cell. HGT has been acknowledged within and between diverse life forms ranging from lower to higher organisms such as the Bacteria, Archaea, Viruses, and Eukarya in the hierarchy of life (Dunning Hotopp 2011). HGT can happen in the human and animal gastrointestinal tract. The constitutive CaMV35S promoter is a highly used promoter that overexpresses the desired proteins in plants (Pandey et al. 2019; Srivastava et al. 2018). Conversely, through HGT, it is possible that in the gastrointestinal tract, the constitutive CaMV35S promoter becomes inserted in the human genome and causes some genes to express severely, affecting serious problems to human health. Besides the CaMV35S promoter, there is the likelihood of insertion of a gene that has been transformed in the plants, and toxic nature for insecticidal activity, like Bt transgenics, which form mycotoxins, can harm humans or animals significantly.

4.5 Imminent Scenarios for Transgenic Plants in Insect Pest Management

Pests and diseases cause severe loss to economically important crops, and reduction in such losses through the proper harnessing of molecular biology and biotechnology studies may increase crop yield and productivity. In this light, plant protection depends heavily on chemical pesticides, which is certainly not a sustainable approach as revealed by recent failures against cotton bollworms and several other major crop pests (Carrière et al. 2014). In this regard, integrated pest management (IPM) with a major focus on biological control and other nonchemical methods is strongly recommended by the central and state governments (Kos et al. 2009). However, biological control and use of other nonchemical pesticides remain doubtful among the plant protection practitioners and farmers due to a lack of competent strategies to cover up the efficacy of chemical pesticides. Hence, to overcome the loopholes of pest management, insect-resistant transgenic plants appear to provide the much-needed strength and stability to IPM.

Biosafety concerns, like toxicity, allergenicity, cross-pollination, effects on nontarget organisms including biological control agents, insect resistance, etc., should be thoroughly investigated and justified before the technology is commercialized through the regulatory protocols. The major concern about the possibility of the target pests developing resistance to Bt protein can be overcome by adopting certain insect resistance management (IRM) strategies, like gene pyramiding, optimum dosage, monitoring for resistance, deploying IPM strategies, growing non-Bt crop as refugia, etc. (Anderson et al. 2019; Alemu 2020; Huseth et al. 2020; Zafar et al. 2020).

Transgenic technology can be easily integrated with other control methods, like biological, cultural, mechanical, pheromones, and even chemical pesticides. In consequence, agricultural crop production throughout the world is poised to realize the benefits of transgenics for pest management and quality improvement. Concerns regarding transgenics should be addressed scientifically and uncover the aspects of cost-effectiveness, greater public awareness, and farmer education, which would make this technology more acceptable. The effective dissemination of correct information and proper guidance is a prerequisite to removing any misconception or apprehension about this remarkable new technology (Karthikeyan et al. 2012).

Transgenic plants incorporated with insecticidal genes are set to feature prominently in pest management in both developed and developing countries. Entomologists, breeders, and molecular biologists need to determine how to deploy this technology for pest management and at the same time reduce possible environmental hazards. To achieve these objectives, we need to have a proper understanding of the insect biology, behavior, its response to the insecticidal proteins, temporal and spatial expression of insecticidal proteins in plants, strategy for resistance management, the impact of insecticidal proteins on natural enemies and nontarget organisms, and a mechanism to deliver the technology to the resource-poor farmers. Several such genes are presently being evaluated for their biological efficacy against sorghum shoot fly, *Atherigona soccata*; spotted stem borer, *Chilo partellus*; tobacco caterpillar, *Spodoptera litura*; and cotton bollworm/legume pod borer, *Helicoverpa armigera* (Sharma and Ortiz 2000).

The transmission of zoonotic diseases to humans underlines the biological interaction of living things and could inspire us to grapple with the complexity and uncertainty involved in the conservation of life forms effectively and building social ecological systems that are both resilient and adaptable. Land degradation is extensive in many countries, brought about by heavy grazing, invasion by non-native plants, and unsustainable agricultural and forestry practices. Habitat degradation shrinks the resilience of ecosystems, reducing population sizes, and restricting gene flow; also, many emerging infectious diseases arise from human encroachment into wildlife habitats that activate transmission of diseases from animal populations to humans more likely (Allen et al. 2017; Rohr et al. 2019). Furthermore, the use of GM crops with inbuilt herbicide tolerance (Woodbury et al. 2017) leads to increased herbicide use and associated loss of weeds that support pollinator species (Benbrook 2012). Wildlife-friendly, locally appropriate means of securing food and diversifying livelihoods are needed that support human and ecological health at the same time as conserving the genetic heritage that is in danger of being lost due to agricultural intensification and homogenization (Isbell et al. 2017).

Certain issues, like the development of resistance, performance limitations, insect sensitivity, gene escape into the environment, secondary pest problems, search for new genes, environmental influence on gene expression, and anthropogenic activities, should be addressed well before introduction of transgenic plants into the environment (Sharma and Ortiz 2000). Apart from these aspects, challenges regarding plant conservation are also surfacing, which should be taken into consideration during the application of transgenic plants or the management of insect pests (Le Hesran et al. 2019; Gillson et al. 2020).

4.6 Conclusions

Considering the increasing human population, the rapid change in climatic conditions, and the shrinking arable land area, there is an urgent need for the development of high-yielding crop varieties, which are equipped with nutritional contents and also tolerant/resistant to various biotic and abiotic stresses. The transgenic plant development explains two key groups of discussion, encircling the ethical issues and scientific values. The scientific approach towards the direct solution of the problems that human beings face in the present time duration or the upcoming years is reminiscent of food scarcity. To achieve and fulfill the demands of the huge human population, the transgenic approach in various ways has become a direct solution. But with so many pros, there are some serious cons, which are of course preventable by following some stringent regulations that will protect them from the harsh impacts of transgenic use, and finally their commercialization can be made safer. Further, there is a need to encourage the research and development of plant transformation methods for eliminating the use of selective markers. Another concern of antibiotic resistance genes used in transgenic development may cause a highly negative impact on the environment by increasing antibiotic-resistant microorganisms. To reduce this risk, the FDA (Food and Drug Administration) recommends transgenic plant developers not to employ commonly used antibiotics for disease treatment in humans. Numerous threats of transgenic crops are under examinations scientifically, because ignoring them in the excitement of instantaneous advantages is equally unscientific. Therefore, with the help of a holistic approach, the use of transgenics in crop improvement may be highly recommended for mankind.

Points to Remember

- Insect-resistant transgenic plants offer protection from various insect pest infestations.
- Insect-resistant transgenic plants contribute to high-yield crop production, which is essential for the nutrient needs of the growing human population.
- Despite several advantages of insect-resistant transgenic plants, there is an urgent need to balance the trade-off between the scientific approach and environmental safety issues.

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