Chapter 8
Transgenic Plants and Its Role in Insect Control

Joseph Adomako, Stephen Yeboah, Stephen Larbi-Koranteng, Frederick Kankam, Daniel Oppong-Sekyere, Jerry Asalma Nboyine, Yaw Danso, Michael Kwabena Osei, and Patricia Oteng-Darko

Abstract The issue of food security has gained global significance in both political and social discourse due to a projected worldwide population increase by 2050. A major hindrance to achieving food security is the negative effects of insect pests. Insect pests competes with humans at the highest level for agricultural resources and it is estimated that their activities accounts for between 30–40% losses in food crops globally. For decades, numerous policies aimed at ameliorating the impact of insect pests on crops have been implemented. Prominent among these is the development and use of pesticides. Notwithstanding its effectiveness, this strategy is bereft with serious limitations such as poisoning, environmental pollution and insect pest developing resistance to pesticides. A sure way to defeat the food production challenges in a sustainable manner is to explore the use of new engineering techniques to develop superior crop varieties that are high-yielding, environmentally sustainable, cost-effective to produce and resistant to insect pests. Conventional

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J. Adomako (✉) · Y. Danso
Plant Health Division, CSIR-Crops Research Institute, Kumasi, Ghana
e-mail: joeadomako@gmail.com

S. Yeboah · P. Oteng-Darko
Resources and Crop Management and Socio-economics Division, CSIR-Crops Research Institute, Kumasi, Ghana

S. Larbi-Koranteng
Crop and Soil Science Department, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Asante-Mampong, Ghana

F. Kankam
Department of Agronomy, Faculty of Agriculture, University for Development Studies, Tamale, Ghana

D. Oppong-Sekyere
Department of Ecological Agriculture, Bolgatanga Technical University, Bolgatanga, Ghana

J. A. Nboyine
CSIR-Savanah Agriculture Research Institute, Nyankpala, Ghana

M. K. Osei
Horticulture Division, CSIR-Crops Research Institute, Kumasi, Ghana

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breeding techniques to achieve this may be limited by time and space, hence the need for modern tools for the development of transgenic crops that are resistant to insects attack; these techniques hasten the process of insect pest control strategies in crop husbandry. The adoption of transgenic plants could reduce the usage of pesticides with broad-spectrum effect, in order to reduce the damages they cause. Since its introduction, transgenic plants have been a main tool for managing several insect pests of economic importance successfully. The adoption of such plants will reduce pesticides use. Despite its benefits, there is limited acceptance of transgenic plants globally. Notwithstanding this, the prospects of integrating transgenic plants in crop production to manage the negative effects of insect pests look promising as the demand for safe food and public involvement in evaluating such materials increases.

Keywords Insect pests · Food security · Insect pest management · Transgenic plants · Environmental sustainability

8.1 Introduction

In 2011, it was reported that, the global population was more than seven billion people, with an expected population of up to 9.3 billion by 2050 while per-capita demand for food is likely to increase along with income growth. There is an expected increase in demand for food between 50% and 100% by 2050 (West et al. 2014). The major concern therefore, has been the ability of modern agriculture to support this ever-growing population as it continues to be the concern for policy makers. Meanwhile, crop yield and growth are not sustainable due to reductions in Agricultural research funding, inadequate irrigation systems, and the dependency on rain-fed agriculture. It is therefore imperative that surge in biotic stress, climate change, and human activities pose serious problems to food security (Myers et al. 2017). Hence, tackling hunger remains a major challenge for our generation (Wheeler and Braum 2013). For instance, it is reported that production of cereals globally is to be increased by 56% by the end of 2050 and global production of livestock is also to be up by 90% according to the International Food Policy Research Institute (IFPRI), with developing countries accounting for 93% of cereal and 85% of meat requirement.

Achieving increased food production to meet global demand can materialize by integrating several factors, such as increase in the area of cultivation, use of improved agronomical practices, biocontrol agents, and efficient management of soil and water. In addition to these will be the use of pest-resistant varieties as well as the introduction of transgenic plants that can withstand insect pests and diseases attack (Carvalho 2006). The easiest way to have overcome universal food insecurity was to increase land area for cultivation of crops. This, however, may not be feasible as most arable agricultural lands are unavailable, since they are already in use for different agricultural purposes. The World Bank in 2015, estimated that only 37.3% of the available land worldwide could be used for agricultural production, with 11%

(1.5 billion hectares) considered as arable. Although the Food and Agriculture Organization estimates that about 2.7 billion ha of land area is available to increase crop production, the larger portion of these areas are with harsh geo-climatic conditions; making it difficult to use for farming activities (Tyczewska et al. 2018).

Research indicates that erosion and/or pollution have taken almost a third of arable lands globally over the last four decades (Verheijen et al. 2009), contributing to soil depletion and reduction of soil water retention. (Verheijen et al. 2009). The problem is further exacerbated by the abuse of pesticides by farmers although their use is as a result of increased damages by insect pests. Losses in yield of agricultural productivity due to pests and pathogens is estimated to be between 20 to 40% globally (Oerke 2006; Culliney 2014; Pandey et al. 2017). Also, threats from climate change resulting from increase in temperature and low precipitation have had serious effects on plant growth, increasing availability of carbon dioxide, reducing nutritional levels of our food and at the same time enhancing environmental conditions for the growth of insect pests and disease pathogens.

To overcome global food production challenges in a sustainable manner, it is necessary to explore novel techniques like genetic engineering to develop improved and superior plant varieties such as insect resistant transgenic crops. Genetically engineered crops generally have insect-resistance transgenes incorporated in them that enhance their ability to resist insect pest attacks which has genuinely extended the scope of resistant genes available to plant breeders. Transgenes can be of plant, bacterial, or other origins, and are considered the most ideal since they are highly effective against targeted pest, resilient to adverse environmental conditions, high biodegradability rate, cost effective and less exposure of operator to toxins. Introduction of transgenic plants will therefore reduce the over reliance on broad-spectrum insecticides, and reduce ecological damage these insecticides cause.

Reductions in fertilizer and pesticides usage do not only result in valuable savings for farmers but also improves nutritional quality and health benefits of consumers as no evidence suggest commercial transgenic crops contain allergens other than those in normal foods (Dunn et al. 2017). Therefore, this review examines the importance of insect pests in crop production and the role of transgenic plants in solving the critical challenges of food insecurity resulting from activities of insect pests and the prospects of growing these crops.

8.2 Economic Importance of Insect Pests in Crop Production

For centuries producers have battled with biotics stress more especially with insect pests for food sufficiency to feed both human and animal. The issue of food security has gained global dominance in both political and social agendas due to increasing global population globally projected to be above nine billion by 2050. This has necessitated the development and use of several modern tools to hasten the breeding of superior crop varieties that are high-yielding, and can withstand adverse environmental conditions, and at the same time offer returns on investment. An effective way to achieve this objective, is to reduce losses associated with insect pests in food crop production. As reported by Oerke and Dehne (2004), insect pests are the main competitors with human for agricultural resources, with their activities favoured by monocultures and intense use of fertilizers. The importance of insect pests in food production can never be underestimated as they contribute significantly to global food insecurity and reduced livelihood.

They reduce quality and quantity of crop yield contributing immensely to primary and secondary losses under different (pre and post-harvest) conditions. Primary and secondary pests are the categorization of insects based on their habits and characteristics. The later categorization as primary insects are considered more harmful due to the damage caused to the entire plant and crop derivatives. These insects bore holes into their host plants, which is used as site for oviposition, larval growth and development, as well as serve as avenue for other secondary pathogens to operate. In contrast however, secondary pests are opportunistic agents that feed on processed products or plant tissues previously damaged by primary insects. For centuries, there have been several reports which shows that crop losses globally due to insect pests is immeasurable. Oerke and Dehne (2004) reported that pests account for approximately 10.1% of the total crop losses in potatoes, soybean, rice, barley, maize, sugar beet, notwithstanding the application of control measures. Similarly, the FAO (2019) estimates that between 20–40% of global crop production are lost to pests.

Global loss in food crops is projected to be between 30–40% notwithstanding annual investments on insecticides (Garcı'a-Lara and Saldivar 2016). Despite these direct losses to major crops and their derivatives, they additionally cause indirect losses by contaminating crops or produce with their body parts or exoskeletons, eggs and wastes (Garcı'a-Lara and Saldivar 2016). For years, several insect pests have evolved to biotypes in order to develop resistance to insecticides, host plant or climate change compounding challenges they pose to crop loss. A typical example is the biotype development in aphids, *Aphis craccivora* that causes severe damage in cowpea and groundnuts, especially under drought conditions. Similarly, several species of whiteflies and the cassava hornworm are known to cause enormous damage to cassava production (Bellotti 2008). It has been reported that high population densities of *B. tabaci,* can cause reduction in root yield of cassava as the insect feed directly on the cassava crop (Liu et al. 2007). Similarly, reports indicate that the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero can cause tuber yield loss by 80% during production (Nwanze 1982). An intensive agricultural production systems will mean the evolvement of biotypes with its attendant effect. Finding eco-friendly means of mitigating their effects are of crucial importance to sustain the environment.

8.3 Strategies for Insect Pest Management

Pest management strategies are mainly established to minimize both field and post-harvest losses in crops. According to Isman (2019), pest management tools can be classified into several categories although none can be used to singly solve insect pest problems despite the success driven by individual tools. According to Oerke and Dehne (2004), crop protection is inefficient in food crops, making insect pests more severe than in cash crop production.

Over dependence on synthetic pesticides to manage the stress of insect pests are environmentally unfriendly, unsustainable, and unprofitable to use by several farmers in developing countries. Apart from these, abuse of pesticides has proven harmful to human beings, beneficial and non-targeted organisms and have led to insect species developing resistance to pesticides. Notwithstanding this, chemical pesticides are the most widely used control strategy. It does not only provide a rapid, effective and dependable pest management approach but also an economical means of controlling insect pest's complex.

To reduce the negative effects of chemical pesticides, research has focused on the development of more selective agents (Eason et al. 2014) that will depart from highly persistent and broad-spectrum products. Also, the search and development of biological insecticides meant to improve environmental safety have been on the ascendancy. Such insecticides act on their target organisms through either direct contact as in aerosol or will require the insect ingesting it during feeding as in the case of *Bacillus thuringiensis*. Apart from these, there are others that are taking up systemically, acting on the vascular systems of plants like in the case of the neonicotinoids and other like the insect growth regulators (IGRs) and ecdysone that disrupt pest development by acting on their endocrine systems (Goldson et al. 2015).

The use of pheromones or other attractants alongside toxicants and a carrier material are used with the objective of attracting insect species to formulations to cause their mortality after eating (El-Sayed et al. 2009). This approach has gained popularity because the toxins on contact kills a few insect species other than the target insects. Another advantage of such insecticides is that they are applied at lower rates than their counterparts that require a spray application. Despite the success in pesticides usage, acquisition of resistance by insect pests remains a source of concern. Resistance acquisition is a natural phenomenon that occur as a result of frequent genetic changes among population over time. However, in a polymorphic population, some individuals are pre-adapted to cope with selective agents, especially when they do not get exposed.

Introduction of natural enemies (insect predators, parasitoids) or biopesticides have been successful in controlling invasive pests (Jackson 2007). According to Hajek and Eilenberg (2018), a significant reduction in populations of pests by biocontrol agents have been achieved. The use of biological control agents requires periodic releases of such organisms and providing a natural habitat for such insects and avoiding practices that will negatively influence their survival to be able to control the endemic pests. Even though biocontrol has been successfully used in greenhouses (Surendra 2019) and sometimes in the field (Zalom et al. 2018), much effort is require to promote the practice. A success story is the control of cassava mealybug using parasitic wasp *Anagyrus lopezi* (Aekthong and Rattanakul 2019).

The employment of cultural control strategies to manage insect pests is environmentally sound and beneficial to farmers. Dara (2019) defined cultural control practices as the manipulation of agronomic practices to minimize effects of pest infestations and damage on crops. This method is also known as the traditional pest management practices due to its long-standing nature, usually by small-scale farmers. This method of pest management relies solely on the characteristics of the cropping systems of a particular environment, use of crop associations, traps, manipulation of planting and harvesting times and field sanitation techniques to reduce insect pest attacks.

Genetic diversity plays an important role in insect pests' management. Growing more than one crop using same piece of land as an improvement on the monocropping system is a sure way of maximizing crop diversity. Cultivating more than one crop is ecologically complex due to the interspecific and intraspecific competition with any prevailing insect pests and natural enemies. Insect pests' population densities are usually low in polycultures due to associational resistance or resource concentration and activities of predators. Varying time for planting and harvesting as a way of avoiding pests during critical stages of crop production is a sure way to avoid damages cause by pests. There are reports on reduction of infestation levels of aphids, thrips and pod bug due to the early planting of cowpea in Uganda. There is a similar report in Nigeria by Asante et al. (2001) which suggested reductions in pod borer (*Maruca vitrata*) flower thrips (*Megaluro thripssjostedti*), and the pod sucking bug (*Clarigrallato mentosicollis*) incidence. The difficulty or poor understanding of the traditional agricultural systems, difficulty in observing and the limited understanding of the insect pest ecology are major constraints to the use of cultural practices to manage insects by farmers (Laizer et al. 2019).

Identification and use of alternative insect control approaches such as resistant host plant has been explored and provided some level of success in insect pest management. For years, the strategy has depended on the use of traditional breeding techniques to develop cultivars that are resistant or tolerant to pests. Some of the characteristics possessed by these cultivars are morphological, physical or biochemical traits that reduce their attractiveness or its suitability for the pest to feed successfully to enable them to develop and reproduce. Resistance of host plants to insects occur naturally which confers on plants to defend themselves against insect pests' attack. This phenomenon helps both the insect and the plant to co-evolute and co-exist (Kalode and Sharma 1995). Numerous sources of resistance have been found and resistant genes introgressed into different high yielding crop cultivars.

Unlike synthetic chemical and biological control strategies, the use of crops varieties that are resistant to insect pest are not affected by environmental conditions. The contribution made by the application of plant varieties with resistance to pests for sustainable crop production cannot be over-emphasized. Developing crop varieties with resistance against insect pests using conventional means is time-consuming. It is reported that developing the midge-sorghum resistant variety, ICSV 745, took not less than 15 years while that of spotted alfalfa-aphid resistant varieties took between three and 5 years (Sharma 1993; Panda and Khush 1995). Traditionally, identifying host-plant resistance plays fundamental roles in insect pests' control, however, its advancement has been slow due to the low yield potential of the developed resistant crop varieties because of a linkage drag (Smith 2005). Again, developing resistant cultivars against insect pests through conventional breeding techniques is limited by time constraints. To overcome these challenges, transgenic breeding strategies have widely been accepted as an important tool in crop improvement to produce crops that can produce insect resistance genes.

8.4 Role of Insect Resistant Transgenic Plants in Crop Production

It is estimated that approximately 40 different insect-resistant genes have been inserted into crops such as broccoli, corn, cotton, rice, soybean and several others (Table 8.1) to control insect pests and increase productivity. Such genes obtained from microorganisms, plants, and animals have proven to be advantageous in controlling pests compared to conventional insecticides. Microbial sources of insecticidal toxins include bacteria and fungi. Remarkably, these secondary metabolites produced by different strains have served as microbial insecticides for several years in IPM package. (Schuler et al. 1998). So far, *Bacillus thuringiensis (Bt)* insecticides have proven to be economically and ecologically successful and provided exceptional achievements in transgenic technology. Crystal protein endotoxic genes produced by different strains of *Bt* are selective and are specific in its action as an insecticide to the lavae of different insect groups: whiles *Cry1* and *Cry2* are specific to lepidopteran, Cry2A *is* toxic to both lepidopterans and dipterans, and *Cry3* is specific to the coleopterans (Malone et al. 2008). These crystal proteins are solubilized and activated by an enzyme, proteinases after a susceptible insect ingest these transgenic plants into the insect midgut. Although the actual process involved in the insect-killing is not fully understood, some studies, such as Schünemann et al. (2014) reports that there is a binding process between activated toxins to the receptors in the epithelium on the insect midgut which is inserted into the membrane of the insect midgut. This triggers disruption of the electrical K1 and pH gradient thereby creating pores which ultimately results in irreversible midgut-wall damage. Similarly, there are also two genes that have been transferred from the bacteria *Agrobacterium tumefaciens* and the genus Streptomyces ie Isopentenyl-transferase gene (*ipt*) and a cholesterol-oxidase gene respectively into tobacco to confer resistance against economically important crop insect pests.

According to Gatehouse (1991), the plant sources exhibiting insecticidal activities, are classified into two groups consisting of (1) protein antimetabolites (example

Table 8.1 Some transgenic crops, inserted genes and their targeted insects

Crop	Inserted gene(s)	Targeted insect(s)	Reference
Broccoli	*CryIAa*	*Plutella xylostella*	Kumar et al. (2018)
Brinjal	*Cry1Ac*	*Leucinodes orbonalis*	Shelton et al. (2018)
Chickpea	*Cry1Ac, cry2Aa*	*Helicoverpa armigera*	Acharjee et al. (2010) and Acharjee and Sarmah (2013)
Chinese cabbage	*Cry1Ac*	*Plutella xylostella*, *Trichoplusia ni*	Cho et al. (2001)
Cotton	*CryIAc, Cry2Ab*	*Spodoptera frugiperda Anthonomus grandis*	Siddiqui et al. (2019)
Corn	*Cry1Ab, Cry1Ac, Cry1Ah*	*Helicoverpa armigera*, *Ostrinia furnacalis* and *Chilo suppressalis, O. furnacalis*	Xue et al. (2008) and Sun et al. (2015)
Rice	*Cry1Ab* *Cry 1Ac* *Cry2AX1*	*Scirpophaga incertulas, Cnaphalocrocis medinalis, Mythimna separata*	Lu (2010) and Chakraborty et al. (2016)
Sorghum	*Cry1Ac*	*Chilo partellus*	Girijashankar et al. (2005)
Sugar cane	*Cry1Ab* *cry1Ac*	*Diatraea saccharalis*	Wang et al. (2017) and Dessoky et al. (2021)
Soybean	*CryIAc, CryIAb, CryIF*	Lepidopteran insects	Koch et al. (2015)
Tomato	*Cry2Ab, Cry1Ab*	*Helicoverpa armigera* *Spodeptera litura*	Saker et al. (2011) and Koul et al. (2014)
Potato	*Cry3A*	*Leptinotarsa decenlineata*	Mi et al. (2015)
Cowpea	*Bt (vip3)* *Cry1Ab*	*Maruca vitrata*	Bett et al. (2017) and Addae et al. (2020)

proteinase inhibitors, α-amylase inhibitors, lectins and arcelins) and (2) non-protein antimetabolites (alkaloids, non-protein amino acids, terpenoids, retinoids (isoflavonoids), tannins, polysaccharides, glucosinolates, and cyanogenic glycosides). The production of these antimetabolic proteins act on the insect's digestive processes to protect the plants against insects. Proteinase inhibitors from plants constitute integral part of plant's natural defense against insect attacks (Larry and Richard 2002). Second type of enzymes used as inhibitors to modify crop plant is the α-amylases. The pea resistant to the Bruchid beetles, *Callosobruchus maculatus* and *C. chinensis* was as a result of the introduction and expression of the bean a-AI gene under the control of the 5′ and 3′ regions in the bean phytohemagglutinin gene (Shade et al. 1994). Lectin is a carbohydrates-binding protein and is commonly found in storage tissues and seeds of some plants (Babu et al. 2003). Depletion of essential amino acids caused by the presence of inhibitors is as a result of the activity of hypersecretion of the digestive enzymes of the genes from the plant (Gatehouse et al. 1992) or the midgut-epithlial cells binding of lectins of the insect (Gatehouse and Hilder 1994). Wasp, spiders, mammals, and scorpions constitute the sources of resistance genes from animals whilst genes encoding neurotoxins from predatory mites and scorpion (Tomalski and Miller 1991; Stewart et al. 1991) have been used in recombinant baculoviruses to improve their biological activity. Using ribonucleic acid (RNA) interference as a silencer of insect gene have shown potential in improving plant defense system and has proven noble in developing insect resistant transgenic crops. (Baum et al. 2007). Nevertheless, Cry proteins of Bt origin forms the basis of plant defense against insects in most commercially grown transgenic crops (Tabashnik and Carrière 2009).

Cultivation of insect resistant transgenic plants does not need protection with other insects, leading to minimal environmental effect, prevention of the health hazards during the application of insecticides, and developing insecticidal resistance. Research has pointed to the fact that transgenic plants have negligible or no side effect against birds, mammals as well as human beings (Goldberg and Tjaden 1990). The deployment of insect-resistant transgenic crops according Wu and Guo (2003) plays tremendous role in the conservation of biodiversity as has been found in *Bt*-fields compared to fields treated with synthetic insecticides. Again Wu and Guo (2003) found an increase in population of natural predators against aphids in fields cultivated with Bt cotton compared to non-Bt cotton fields. Several improvements have been made in developing and mass cultivation of transgenic crops to minimize pest damage in both food and non-food crops since the first transgenic plant, expressing insecticidal gene was produced in 1987.

A contributory factor to the intense development of transgenic plants for the control of insect pests has been the tremendous resistance of insect pests to chemical pesticides. To overcome this, there have been several Bt toxin genes introduced into crops, such as tobacco, maize, rice, potato, apple, cotton, and tomato, to confer resistance to specific insects. Bt crops initially developed mainly of cotton and maize, producing Cry1Ac and Cry1Ab toxins, respectively (Tabashnik and Carrière 2009), which were biocidal to lepidopteran pests. Following the successful research and limited production in 1987, universal cultivation of *Bt* crops has risen. An area of about 148 million hectares of transgenic crops were cultivated globally in 2010 increasing to 185.1 million ha in 2016 across 26 countries with 19 of these coming from developing countries (Abbas 2018). An average of more than 99.0 million hectares of land was cultivated of transgenic crops in developing countries in 2016 compared to 85.5 million ha in industrialized countries in the same period. Commercialization of transgenic crops resistant to insects actively commenced around the middle of 1990, when transgenic cotton, potato, and maize plants exhibiting the ability to kill insect with toxin d-endotoxin, produced by the *Bacillus thuringiensis* genes (Gatehouse 2008).

Monsanto, in 1996 pioneered the development and commercial production of the first insect-resistant transgenic cotton (highly effective in the control of Lepidoptera pest compared to synthetic insecticides (Betz et al. 2000). Since then, several transgenic crops have been developed to manage significant pests. Recently, approval was given for use in Bangladesh four Bt eggplant resistant to insects as well as a *Bt* soybean variety expressing Cry1Ac + Cry1Ab for the control of the lepidopteran in Latin America (Koch et al. 2015). *Bacillus thuringiensis* sweet corn, the most adapted transgenic vegetable with resistance to the insect pest, *Heliothis zea* according to Shelton et al. (2013) produces cleaner ears comparable to maize cultivars using chemicals. Again, the cultivation of transgenic maize with resistance to the European corn borer (*Ostrinia nubilalis* Hübner) and the western corn rootworm (*Diabrotica virgifera virgifera* LeConte) as well as other coleopteran species are reported to have reduced yield losses caused by these pests without using toxic organophosphate insecticides (DeVilliers and Hoisington 2011). Also, there is a report on the reduction of cotton pests significantly following the cultivation of Bt cotton (Naranjo 2011). Transgenic tomatoes have also been reported to protect either tomato fruit worm (*Heliothis zea*) and tobacco hornworm (*Manduca sexta*) or tomato fruit borer (*Helicoverpa armigera*) (Mandaokar et al. 2000; Kumar and Kumar 2004). Tomato plants containing *Bacillus thuringiensis* subsp. *tenebrionis* (*B.t.t.*) toxin caused a significant insecticidal activity against Colorado potato beetle larvae and under field conditions Kumar (2004) found that *Bt* tomato was effective in managing *Manduca sexta*, *Keiferia lycorersicella*, and *Helicoverpa armigera.* In addition to these, insecticidal activity of transgenic brinjal fruits against larvae of the fruit borer (*Leucinodes orbonalis*) have been documented (Kumar et al. 1998).

Insect-resistant crops developed initially, however, expressed dominant *Bt*-*Cry* genes, producing single *Bt*-toxin against specific lepidopteran pests, thereby killing a limited set of target pests. This narrow range of action led to the evolution of insect resistance crops, a major setback to the use of this technology. To overcome this limitation, *Bt*-crops producing multiple toxins have been developed by stacking *Cry* genes, targeting multiple receptors in insect pests to provide broad protection to a range of insects, delaying pest resistance development (Christou et al. 2006; Gatehouse 2008). The important role of transgenic crops in sustainable food production systems in sub-Saharan Africa is gradually gaining ground even though their utilization is limited and remains controversial in almost all countries in SSA and other developing countries. Although adopting transgenic crops may not solve all of the continent's food production constraints, adopting the technology will be highly beneficial to crop producers in the region. Currently, few countries in Africa have seen large-scale adoption of transgenic crops, although the continent has witnessed a fair share of insect infestation. According to Adenle (2011) about 15 million farmers estimated to be 90% who planted genetically modified crops were from three developing countries such as Burkina Faso, Egypt, and South Africa, were resource-poor farmers. These three countries together planted about 2.5 million hectares of transgenic crops (James 2011) with Kenya, Nigeria, and Uganda having commenced field trials although Falck-Zepeda et al. (2013) reported that Africa contributed less than 1.6% of the total land area cultivated to transgenic crops in 2011. Since then, the drive-in Africa to grow engineered crops is on the rise with Ethiopia, Nigeria, Kenya, and Malawi approving the planting of insect-resistant cotton (ISAAA 2020).

South Africa is considered the first African country to commercially produce insect's resistant *Bt* cotton to manage insects such as the bollworm infestation, control insect resistance to chemicals and reduce insecticidal use in cotton production (Gouse 2013). Reports indicated that research on *Bt* cotton in South Africa have increased yield and total reduction in chemical expenditure following adoption and commercialization of *Bt* cotton compared to the traditional varieties (Fok et al. 2007). Maize is an important cereal crop in the continent with a high insect infestation rate. The introduction of *Bt* maize with Bt gene (Cry1Ac), has been reported to show great prospects to control *B. fusca* and *C. partellus* in the production of the crop. Like *Bt* cotton, *Bt* maize has recorded higher yields compared to conventional cultivars with lower pesticides cost (Brookes and Barfoot 2008; Gonzales 2002; James 2002). Another challenge to insect damage on crops is the predisposition of their host to secondary infections by other pathogens. Wounds created on the kernels of maize favours fungal colonization thereby exposing them to mycotoxin contaminations. Transgenic insect-resistant (*Bt*) maize has been found as a potential way of reducing fumonisin exposure (Gouse 2013) due to a reduction in fusarium colonization arising from minimal entry points created by insects such as Lepidoptera.

8.5 Limitations to the Adoption and Utilization of Transgenic Plants for Insect Control

Since the advent of using genetic engineering to produce modified crops for human use, public perception of transgenic plants and their recognition in food production has been met with a mixed reaction. The controversy surrounding transgenic products have inspired global public debate on its acceptability and use by farmers in several countries. Advocates of the technology highlights benefits for society through hunger reduction, starvation prevention, and biotic stress management whilst opponents often see it as interference with nature which has dire consequences, disastrous to human genetics and natural ecosystems (Nelson 2001). In addition to these, there is also the fear in developing countries that adoption of transgenic crops, is likely to lead into farmers permanently depending on multinational companies for seed and chemical with the potential of favoring the industrialized countries (Junne 1991).

Despite the entry of transgenic crops into the food system of several countries, public acceptance remains an important factor affecting the future of technology. Notwithstanding, several factors against the adoption of transgenic crops, lack of education and provision of information on risks and benefits associated with the technology can also influence its acceptability. Baker and Burnham (2001) found socioeconomic variables as insignificant, but consumer's cognitive variables as significant determinants for embracing genetically modified food products.

Generally, the adoption of genetically modified crops are widely cited as a solution to combat pest resistance in crop production, yet this technology faces challenges in managing insect pest complexes. Threats of the evolution of resistance to *Bt* in targeted pest lingers on. A resurgence of the pink bollworms in India, and the mutation of corn leaf worms to develop resistance in Brazil are some avenues of concerns and opposition to use of insect-resistant transgenic crops. The long term effects of transgenic plants on agro-ecosystems still needs further understanding. The challenge is that insect species susceptible to expressed toxins, can develop into secondary pests and cause severe damage than initially would. Secondary pests which hitherto were of minor importance might assume major importance. In mid-southern and southeastern cotton-producing regions of the USA, Naranjo (2010) reported higher incidence in minor insect pests such as aphids, leafhoppers, mirid plant bugs, and stinkbugs considered initially as secondary pests in cotton production. Similarly, reduction in insecticide sprays in India has been linked to the prevalence of mealybugs (*Pseudococcus corymbatus*, *Pulvinaria maxima*, and *Saissetia nigra*), thrips (*Thrips tabaci*), and leafhoppers (*Amrasca biguttula biguttula*) in cotton production (Sharma 2005). In effect, reduction in the use of chemical insecticides in Bt cotton production have resulted in upsurge of pests that were not susceptible to *Bt* protein and were initially controlled by pesticides. Reductions in natural enemies' populations and interspecific competition with the target pest according to Mabubu et al. (2016) are some factors that may contribute to the outbreak of secondary pest species with the use of *Bt*-crops.

8.6 Integration of Transgenic Plants into Integrated Pest Management Strategies

As the limitations of completely depending on transgenic plants in insect control continue to expand, utilizing the technology in an IPM) approach will ensure food security, sustainable Agriculture and the protection to the environment. The FAO (2018) defines IPM as "careful use and intergration of all pest control measures that discourage pest population development, reduce pesticides use and other interventions to economically justified levels to reduce human risks as well as the environment. Generally, *Bt* crops have been categorized as either vehicle to deliver selected insecticides or to induce host plant resistance which will affect the growth and development of insects (Naranjo 2010).

Several regulatory agencies, including the United States Environmental Protection Agency (USEPA), as one of the several regulatory bodies, considers *Bt* protein as a "plant-incorporated protectant" (PIP), that regulate transgenic plants with pesticidal properties similar to any synthetic or organic pesticide (Naranjo 2010) sparking the debate as to whether it can fit into the description of host plant resistance, a strategy of integrated pest management. *Bt* crops, according to Naranjo (2010) are considered prophylactic control since *Bt* proteins are continually produced and released by *Bt* crops irrespective of insect infestation. Prophylactic measures are, however, good components of IPM since the concept embodies preventive and prescriptive measures consisting of strategies leading to pest avoidance. Genetic engineering overcomes the limitation of conventional breeding by accelerating host plant resistance breeding processes through recombination of specific genetic material followed by crossing into multiple elite lines. In line with this, genetically engineered crops can be viewed as a form of host plant resistance, highly recognized as a key component of IPM (Kennedy 2008). Host plant resistance developed through traditional breeding process or genetic engineering plays valuable role in IPM and complements different pest management practices.

The principle of IPM hinges on three main control principles viz. biological, cultural control, and host plant resistance. With the biological control, the abundance and the activities of natural enemies are enhanced to suppress pest population. Whilst host plant resistance involves the selection of crop cultivars that have highest pest resistance, cultural control strategy involves all agronomical practices that modify the environment making it less favorable for pest invasion. When there is sufficient combination of all these three control measures, put together, then there could be rational consideration of pesticide use in the IPM strategy (Koul et al. 2004; Romeis et al. 2008).

A well design IPM approach ensures rational use of all approaches that complement each other to eliminate over reliance of any single approach to achieve comprehensive control of pests. Genetically engineered crops are technically resourceful element of IMP that when integrated properly into a cropping system will enhance profit of stakeholders while reducing risks. Integration of transgenes in insect pest management strategies has successfully been implemented in managing insect pests. Integration of refugees, in the cropping system, improves the resilience of *Bt* traits in genetically engineered plant systems. Current technology allows the deployment of sterile insect technique (SIT) and/or pheromone-based mating disruption by refugees crops (Anderson et al. 2019). Cotton growers successfully planted Bt cotton cultivars without planting refuges but supplied them through targeted and proportional release of sterile male pink bollworm moths over *Bt* and non-*Bt* fields throughout Arizona. This process contributed successfully to destruction of the bollworm pest and the lifting of a ban on US cotton (USDA-ARS 2018). Training stakeholders about the contribution of IPM tactics and ways to include genetically engineered crops into agricultural system remains a priority. Knowledge of the socioeconomic factors should be combined with knowledge in agricultural systems to promote strategies that will drive the adoption and acceptance of insect-resistant transgenic plants in IPM.

8.7 Current and Future Research Techniques in Transgenic Crops Development for Insect Pest Management

The creation and commercialization of transgenic plants resistance to major insect pests have been the major achievements of plant biotechnology. Currently, genes that express insect resistance in transgenic plant are not only derived from the bacterium *Bacillus thuringiensis*, but other genes associated with higher plants, particularly genes encoding inhibitors of digestive enzymes and lactin (Schuler et al. 1998). Knowledge into insect resistant transgenic plant technologies keeps increasing very fast, with substantial research in every sector of our economies.

Modeling studies predicted doom for the sustainability of the technology in global agriculture because of the fear of insect developing resistance to single insecticidal gene products. These dreadful predictions notwithstanding, the worse has not yet happened whilst the introduction of transgenic insect resistant crops keeps increasing steadily over the years. To ensure the permanence and ability to sustain resistance, new approaches are being considered. This suggests that the future of transgenic crops for insect crop management in food production, and storage is promising and as new innovative strategies that ensure longevity of the next generation of insect-resistant plants should be in place.

Successful constitutive *Bt* genes expression has been reported, whilst tissues-specific expression has proven a better option in some cases, this is what happens with the epidermal cell which first suffer an attack from sap-sucking insects. Reports show that transcription elements or chemical induction can be used to regulate expression. It is therefore possible to use this technique to create parts of the plant where there will be no expression of genes and therefore the plant acts as a non-genetically refuge (Christou et al. 2006). For example, the chloroplasts where plastid expression occur, could be target and used for future transgenic crops development (Bock 2007). This is because the plastids accumulates high levels of toxins of bacterial origin just as the *B. thuringiensis* genes (McBride et al. 1995). Another way to improve insect resistance is through gene stacking or pyramiding where multiple genes of interest are inserted into a single plant.

Recently, crops expressing several Cry genes to target single insect (Christou et al. 2006) and the development of hybrid Cry proteins to improve toxicity and host range are being evaluated with the aim of slowing down the development of resistance. The combination of the Cry genes and plant lectins to target various pest has also been reported with the snowdrop (*Galanthus nivalis*) lectin for example fused to Cry gene, to deliver protein to heamolymph of lepidopteran larvae.

New engineered transgenic maize with six resistant genes to control corn rootworm and lepidopteran pest and dual herbicide tolerance genes, has been developed to provide a "one-stop solution" to both pest and weed problems through gene stacking (Grainnet 2007).

Transgenic insect-resistant technologies have been a major scientific success in modern plant biotechnology. Notwithstanding this, there are restrictions on these products in many developing countries, due to the lack of understating of the technology and the lack of mechanisms to regulate its deployment. (Paarlberg 2002, 2008). Usually, the problem confronted public institutions of developing world to develop product for farmers, is the insufficient potential gains that will be accrued which eventually make commercialization difficult due to high price. It is for this reason that most of the developed commercial product of genetic engineering are in the hands of big companies.

8.8 Conclusions

Genetic engineering technologies have transformed crop production remarkably with the introduction of insect resistant crop plants that are high in productivity to benefit resource-challenged crop farmers. Introduction of transgenic crop plants has a limited uncontrolled application of chemical insecticides which endanger man, animals, and the environment in some advanced and developing economies. Transgenic crop plants have been employed in crop production to manage many insect pests of economic importance. Research in transgenic crops may offer new means of improving agriculture, especially in Africa and the world in general. However, a major challenge of transgenic research, apart from obtaining transgenic materials or resources, is to adequately understand physiological expression at the plant level of the inserted genes. An all-inclusive approach that integrates genetically engineered crops and other strategies to manage insect pests provides a sure way of producing safe food to feed the growing population. There should be a sustained education and awareness creation targeted at opponents of transgenic engineering for crop improvement so that the technology would be embraced as a whole to benefit mankind.

Conflict of Interest Authors declare no competing interest. All references have been duly cited and authors acknowledged.

Ethics approval and consent to participate.

Not applicable.

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