Management of Pests Using Genetic Tools in Africa

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Abstract

African farmers are facing numerous natural disasters, such as flooding, fires and extended droughts. In addition, crop pests have had major impacts on yields for several decades. At the same time, farmers continue to explore pest management strategies that are not only affordable but safe and sustainable. Here we review the knowledge from genomics, molecular plant biology and molecular genetics and how these can complement traditional agricultural practices to enhance productivity by offering protection against insect pests. Elsewhere, modern genetic tools and technologies have been utilized to reduce agricultural pest impacts and improve yield. In Africa, this uptake is more recent, with a significant increase in integrated pest management (IPM) or IPM-related research conducted by various national programs and international agricultural research centres over the past few years. Research in Africa has mainly emphasized host plant

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resistance breeding techniques, classical biological control, chemical control and cultural control measures. There is thus an urgent need for African governments to consider investing in biotechnology and genetic advancements tools—in the field of agriculture—to ensure protection off crops from pests and in doing so ensure food security on the African continent.

Keywords

Genetically modified organisms · Integrated pest management · Genetic engineering · Sterile insect technology

10.1 Introduction

The United Nations (UN) projections indicate that the world population is expected to reach at least 8.6 billion people in 2030, 9.8 billion people in 2050 and 11.2 billion people in 2100. This growth in the world's population poses challenges in addressing hunger, poverty, health and education. In fact, global food demand is expected to increase by 60% by 2050 compared to the current level. This rise will be much greater in African, as the African population is predicted to increase 2.5-fold by 2050 (Van Ittersum et al. 2016). Despite this, a large proportion of farmers in Africa still uses traditional agricultural practices, which may be inadequate to meet this increasing demand for food. In addition, agricultural pests account for 30–60% crop yield reduction per annum (Oerke 2006).

In Africa, both indigenous and alien insects in agro-ecosystems are responsible for causing significant economic losses in the agricultural sector (Pratt et al. 2017), for example, the pink bollworm *Pectinophora gossypiella* (Saunders) from Asia, which became a major pest in African countries in the twentieth century (Naranjo et al. 2002). Similarly, the Mediterranean fruit fly ('Medfly') *Ceratitis capitata* (Wiedemann) is a native pest with widespread distribution in the continent, causing damage to more than 250 crops plant species and is considered one of the world's most economically important pests (CABI 2016). Also, in Africa, intercontinental movement of pests is observed causing significant damage to the agricultural crops (Yaninek 1988).

In recent times, Africa is facing an increased introduction of new pests due to the rapid increase in human movements linked to the increase in trade and other commercial activities (Goergen et al. 2016). Subsequently, many of these pests are alien species (Zethner 1995) that are able to establish successfully due to favourable climatic conditions (Satishchandra and Geerts 2020). Many alien species such as *Chilo partellus*, *Cosmopolites sordidus* and *Plutella xylostella* are already well established in these regions. Together with these relatively new alien pests, many indigenous pests are important: *Busseola fusca*, *Coniestaigne fusalis*, *Heliocheilus albipunctella*, *Helicoverpa armigera*, *Sesamia calamistis*, *Ophiomyia spencerella* and several grasshopper species.

Besides Africa being endowed with varied agro-ecological climatic conditions, which range from deserts to tropical areas suitable for different types of cropping

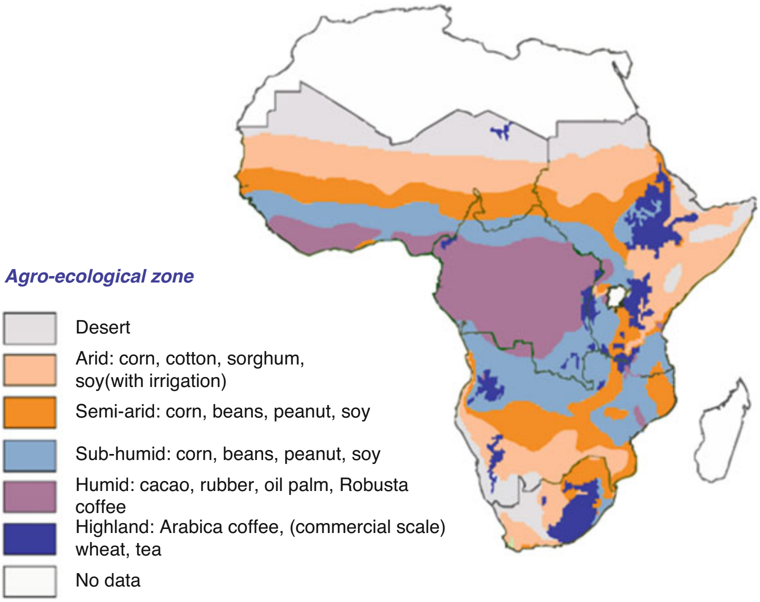

Fig. 10.1 Varied agro-ecological zones of Africa supporting different types of cropping systems (Source: FAO, Robobank. https://economics.rabobank.com/publications/2015/december/sub-saharan-africa-importance-of-institutions-for-developing-food-and-agriculture-value-chains/)

systems (Fig. 10.1), African farmers continue to face challenges when it comes to food production. Farmers find it difficult to control and manage plant-parasitic nematodes, especially root-knot nematodes (RKNs); viruses (i.e. cassava mosaic virus and maize streak); parasitic weeds (Striga); weevils and stem borers. Small-scale farmers in Africa suffer large economic losses because of these agricultural pests. Multilevel approaches are needed to overcome the damage caused by insect pests. In particular, since agriculture significantly contributes to the gross domestic product (GDP) of many African countries (Fig. 10.2). In this chapter, novel genetic tools as an option for pest management are reviewed. Together with this, we briefly discuss policies from African governments towards the development, research and use (adoption) of genetically modified (GM) crops. Furthermore, we evaluate their limitations and challenges in this regard.

10.2 Pesticides to Control Crop Pests

In sub-Saharan Africa half—or 175 million people–of the total labour force is employed by agriculture (IMF 2012). This is because approximately 80% of agriculture constitutes smallholder farms (Alliance for a Green Revolution in Africa 2014). But Africa also has the lowest agricultural productivity per unit area of land, leaving significant room for improvement (OECD/FAO 2016) (Fig. 10.3). African

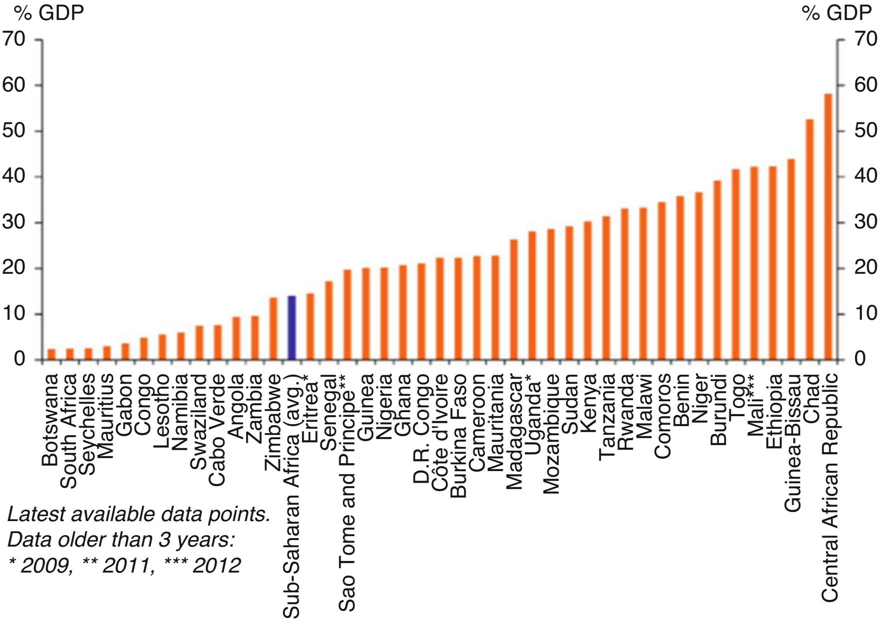

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Fig. 10.2 Agriculture contribution for the GDP of the country (Source: World Bank, World Development Indicators)

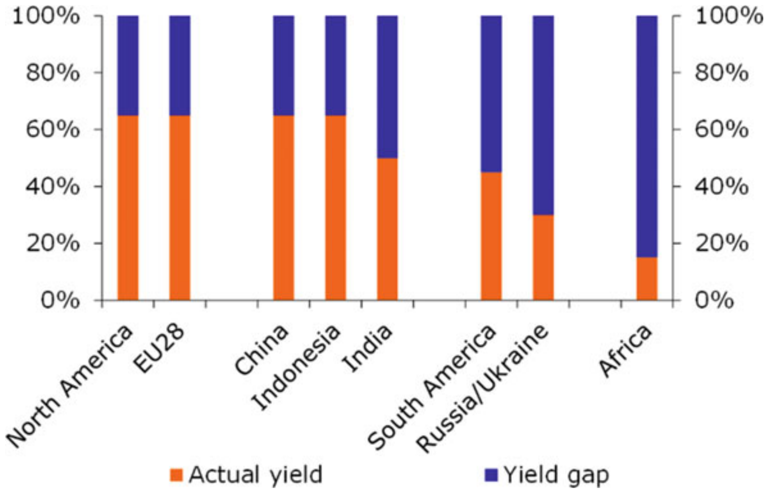

Fig. 10.3 Actual crop yield versus yield gap of Africa compared with other regions (Source: FAOSTAT)

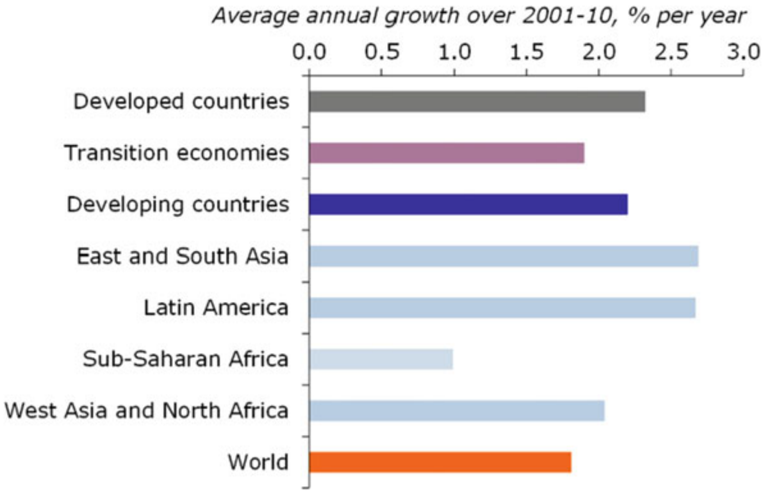

Fig. 10.4 Average annual agricultural growth of different regions (Source: USDA, Economic Research Service, derived from Food and Agriculture Organization of the United Nations and other agricultural data using methods)

countries also have the lowest agricultural growth in productivity compared to other regions of the world (Fig. 10.4). Partly since pest management practice is considered as a built-in process for the production of the crop rather than a separate, well-defined activity.

To date, chemical control through the use of pesticides has been the main method of dealing with agricultural pests and diseases (Aktar et al. 2009). The term pesticide refers to a wide range of compounds including insecticides, herbicides, fungicides, nematicides, molluscicides, rodenticides and others and is formulated to kill or repel a pest or hinder its reproductive capacity (Gilden et al. 2010). Furthermore, pesticides must be fatal to the targeted pests, but as far as possible not to non-target species (e.g. non-pests, man and the environment). According to Aktar et al. (2009), the introduction of other synthetic insecticides such as organophosphate insecticides in the 1960s, carbamates in the 1970s, pyrethroids in the 1980s and herbicides as well as fungicides in the 1970s–1980s significantly contributed towards pest control and increased crop production. Currently, one-third of the world insecticide market is dominated by neonicotinoids and fipronil (systemic insecticides) (Simon-Delso et al. 2015), whereas organophosphate glyphosate is widely used as weed killers (TMR 2014). African countries account for only 3% of world pesticide consumption, of which South Africa alone accounts for up to 2% of total pesticide consumption (Zhang et al. 2011).

It is well established that novel techniques that range from molecular genetics, genomics and molecular plant biology could complement the conventional agricultural practices in Africa to enhance agricultural productivity. Although farmers and scientists have employed plant selection and breeding techniques to enhance the crop yield for many years, currently, the use of techniques such as genetic

Table 10.1 Global status of the greatest number of approvals for GM crops [Source: ISAAA 2018]

GM crop	Event	Number of approvals
HT maize	NK603	61 in 28 countries + EU 28
HT soybeans	GTS 40-3-2	57 in 28 countries + EU 28
IR maize	MON810	55 in 26 countries + EU 28
HT/IR maize	Bt11	54 in 25 countries + EU 28
HT/IR maize	TC1507	53 in 25 countries + EU 28
IR maize	MON89034	51 in 24 countries + EU 28
HT soybeans	MON89788	45 in 25 countries + EU 28
HT soybeans	A2704-12	45 in 24 countries + EU 28
HT/IR maize	MON88017	45 in 23 countries + EU 28
IR cotton	MON531	44 in 20 countries + EU 28
IR maize	MIR162	43 in 23 countries + EU 28
HT maize	T25	43 in 20 countries + EU 28

engineering (GE) help to scale up crop improvement programmes (Gepts 2002). The use of the GE technology allows for plant improvement to confer insect resistance, herbicide tolerance, disease resistance and drought tolerance (Agapito-Tenfen et al. 2014; Mwadzingeni et al. 2016; Srivastava et al. 2016).

For example, managing diamondback moth, Bt biopesticide in the form of sprays has proven successful in many parts of Africa (Furlong et al. 2013). Genetically modified crops express Bt toxins and limit the damage by lepidopteran pests. Bt cotton provides protection against pink bollworm (Carrière and Tabashnik 2001), by expressing Cry 1Ac toxins that are lethal to lepidopterans (de Maagd et al. 2001). Other examples include South Africa that has successfully adopted an area-wide insect pest management method, i.e. sterile insect technique (SIT) to protect crops against fruit flies (Barnes 2016).

According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA) GM Approval Database, there are 33 GM crops currently approved/authorized for use globally. For Africa in particular, there continues to be steady growth in the adoption of GM crops (see Box 10.1 for country details). Different countries have different standpoints on GMO crops. Some African countries allowed GM crops cultivation only in non-food crops, whereas some allowed both food and non-food. The distribution of the number of events per GM crop is shown in Table 10.1. These crops contribute greatly to increasing yield and productivity, reduce agricultural eco-footprints, conserving biodiversity, and mitigate climate change (Pray et al. 2002) (Fig. 10.5). Thus, these factors contributed to African countries' consideration for GMOs adoption and use (Table 10.2). South Africa remains the leading African country in the adoption and cultivation of GM crops, with Sudan and the Kingdom of Eswatini taking the second and third spot, respectively (ISAAA 2018). Furthermore, Nigeria has joined the fold by becoming the first country in the world to approve GM cowpea. Although Burkina Faso and Egypt allow the cultivation of GM crops, they currently have no recorded

Fig. 10.5 Contribution of biotech crops to sustainability (Source: James (2015))

GM crop activities. Research and development on GM crops (14 traits on 12 crops) are ongoing in most African countries to develop crops that withstand environmental challenges and assist farmers with improved yields (Agaba 2019).

Even though GM crops can improve certain plant traits to increase yield and gain a higher resistance against pests, GM crops are not a *silver bullet* to these challenges but offer one of the available solutions. Other solutions, as long-standing examples, are discussed below, Box 10.1. The Kingdom of Eswatini and Nigeria are not included in Box 10.1, given their recent-limited involvement with GM crop activities.

Table 10.2 Current Status of GM Crops in African Countries

Crop	Trait[a]	Gene[b]	Stage of development[c]	Country	Partners[d]
Banana	Bacterial wilt resistance	*Pflp*, *Hrap*	CFT	Uganda	IITA, NARO-Uganda, AATF, Academia Sinica
		pBI-Pflp-Hrap	GHC		
	Pro-vitamin A, iron	*APsy2*, *FROS2*	CFT	Uganda	NARO-NARL (Uganda), QUT
	Nematode and weevil resistance	cry5B, cry6A, col-5-RNAi, cystatins	CFT, GHC	Uganda	Univ. California (San Diego), Univ. Pretoria, Univ. Leeds, Rahan Meristem, NARO-Uganda
Maize	Stem borer resistance	cry1Ac, cry1Ab	Commercialized	South Africa Egypt	
		Bt11	Commercialized	South Africa	
		cry1Ac, cry1Ab, cry1B, cry1E, cry1Ca, cry2Aa	CFT	Kenya	CIMMYT, KARI
	Drought tolerance	*cspB*	CFT	Uganda, Kenya, South Africa	AATF, NARS (Uganda, Kenya, S. Africa, Tanzania, Mozambique), CIMMYT, Monsanto
		XvSap1, *XvAld1*, *XvPrx2* and *XvG6*	GHC	South Africa	Univ. Cape Town
	Maize streak virus resistance	*Rep*$^{1\text{-}219Rb-}$	GHC	South Africa	Univ. Cape Town, Pannar
	Herbicide tolerance	*cp4 epsps*	Commercialized	South Africa	
	Stacked (stem borer resistance and herbicide tolerance)		Commercialized	South Africa	
Sorghum	Pro-vitamin A, iron, zinc protein	RNAi: suppression of phytate, Suppression of safirin	CFT	Kenya, Nigeria	Africa Harvest, Danforth, Pioneer CSIR (S. Africa), Univ. California (Berkeley), Univ. Pretoria, ICRISAT, NARS (Kenya, Nigeria, Burkina, S. Africa), AATF, CORAF/WECARD
			GCH	S. Africa	

Cassava	CMD, CBSD resistance	Hairpin dsRNAs specific to the viral sequences	CFT	Kenya, Uganda	Danforth, KARI, NaCRRI, ETH Zurich
	Pro-vitamin A, iron, protein, reduced cyanides, improved storage qualities	*crtβ* and DXS, *FEA1*, zeolin, HNL, AOX	CFT	Kenya, Nigeria	Danforth, ETH Zurich, NARS (Kenya, Nigeria), IITA
Cowpea	Pod borer resistance	cry1Ab	CFT	Burkina Faso, Nigeria	AATF, NGICA (U.S), CSIRO (Australia), IITA, Monsanto, Kirkhouse, NARS (Nigeria, Ghana, Burkina Faso), PBS (U.S)
Sweet potato	Weevil resistance	cryET33/cryET34, cry7Aa1, cry3Ca1	GHC	Kenya, Uganda	CIP, NaCRRI-, NARL-Uganda, BecA, Kenyatta University, Univ. Puerto Rico, Auburn Univ., Univ. Ghent, Danforthcenter
Rice	NUE, salt tolerance, water use efficiency	AlaAT, *AtNHX1*	Laboratory regeneration		AATF, Japan Tobacco, Arcadia, Univ. California, CIAT, NARS (Burkina, Uganda, Nigeria, Ghana), PIPRA
Cotton	Bollworm resistance	cry1Ac, cry2Ab	CFT	Egypt, Kenya, Uganda	Monsanto, NARS
			Commercialized	Burkina S. Africa	

(continued)

Table 10.2 (continued)

Crop	Trait[a]	Gene[b]	Stage of development[c]	Country	Partners[d]
	Herbicide tolerance	*cp4 epsps*	Commercialized	S. Africa	
			CFT	Uganda	
	Stacked (bollworm and herbicide tolerance)		Commercialized	S. Africa	

[a] *CBSD* Cassava brown streak disease, *CMD* Cassava mosaic disease, *NUE* Nitrogen use efficiency

[b] *AlaAT* Alanine aminotransferase, *AOX* Alternative oxidase, *DXS* 1-Deoxyxylulose-5-phosphate synthase, *HNL* Hydroxynitrile lyase

[c] *CFT* Confined field trial, *GHC* Greenhouse containment

[d] *AATF* African Agriculture Technology Foundation, *BecA* Biosciences Eastern and Central Africa (Kenya), *CIAT* International Center for Tropical Agriculture, *CIMMYT* International Maize and Wheat Improvement Center, *CIP* International Potato Center, *CORAF/WECARD* West and Central African Council for Agricultural Research and Development, *CSIR* Council for Scientific and Industrial Research (South Africa), *CSIRO* Commonwealth Scientific and Industrial Organization (Australia), *ICRISAT* International Crops Research Institute for Semi-Arid Tropics, *IITA* International Institute for Tropical Agriculture, *KARI* Kenya Agricultural Research Institute, *NaCRRI* National Crops Resources Research Institute (Uganda), *NARL* National Agricultural Research Laboratories (Uganda), *NARO* National Agricultural Research Organization (Uganda), *NARS* National Agricultural Research Systems, *NGICA* Network for the Genetic Improvement of Cowpea for Africa (U.S), *PBS* Program for Biosafety Systems (U.S), *PIPRA* Public Intellectual Property Resource for Agriculture, *QUT* Queensland University of Technology (Australia) (Source: http://nepad-abne.net/biotechnology/development-of-genetically-modified-crops-in-africa/)

Box 10.1 GM Crop Scenario in Selected African Countries

i. **South Africa**: South Africa is the leader on the continent in terms of adoption and cultivation of GM crops (ISAAA 2018). *Bacillus thuringiensis* (*Bt*) cotton, *Bt* maize, herbicide-tolerant cotton and soybean are the major commercial GM crops in South Africa (Table 10.2). Cotton is one of the economically most important crops. Bollworms such as *Helicoverpa armigera*, *Earias biplaga*, *E. insulana* and *Diparopsis castanea* are the main pests causing severe damage to cotton (Ismail et al. 2002). In 1997, *Bt* cotton with cry1Ac and cry2Ab—expressing resistance to the cotton bollworm—was commercially released. Since then, farmers started growing *Bt* cotton (NUCOTN 37-B with Bollgard™) (Gouse et al. 2005) and more than 60% of cotton farmers are cultivating *Bt* cotton (Ismail et al. 2002). The majority of the farmers opted for GM cotton as it results in increased yield. Furthermore, the reduction in pesticide application resulted in less pesticide poisoning and a reduction in environmental pollution (Morse and Bennett 2008).

   Maize is one of the main staple crops in South Africa. White maize is a staple food, while yellow maize is mostly used for animal feed (Keetch et al. 2005). Stem borers such as *Busseola fusca* and *Chilo partellus* are the main pests for maize. *Bt* yellow maize expressing cry1Ab was developed during 1998 to control *Ostrinia nubilalis* (Gouse et al. 2005). This gene was then backcrossed with white maize and commercialized in 2001. In 2007, these GMOs were approved by the regulatory bodies (Vander Walt 2008).

ii. **Burkina Faso:** Burkina Faso commercialized GM crops in 2008 and became the second country in sub-Saharan Africa to commercialize GM crops by producing *Bt* cotton (James 2008). Cotton is the most economically important crop in Burkina Faso (Karembu et al. 2009), and *H. armigera* is the major threat to cotton production (Vitale et al. 2011). In 2003, the National Agricultural Research Institute initiated *Bt* cotton (*Gossypium hirsutum*) trials. From 2003 to 2005, field trials of transgenic cotton expressing cry1Ac and cry2Ab genes were conducted, and they showed enhanced resistance against the pest, *H. armigera* with a 15% increase in the cotton yield with a two-third reduction in pesticide usage (Vitale et al. 2008). This success led to the insertion of the *Bt* gene into selected cotton varieties. Currently, more than 115,000 ha of *Bt* cotton is grown in the country (Adenle 2011). After the success with *Bt* cotton, Burkina Faso is working to develop other GMO products such as *Bt* cowpea that is resistant to the pod borer (Maruca).

iii. **Egypt:** Egypt approved *Bt* maize in 2008 and became the first country in Northern Africa to commercialize GM crops (Karembu et al. 2009). Maize is the most important cereal in Egypt. Stem borers are posing severe threats

(continued)

Box 10.1 (continued)

to maize production, and the usage of pesticides results in high costs (Massoud 2010). In 2002, Egypt initiated testing *Bt* maize (Ajeeb-YG) (Ezezika and Daar 2012). During 2002 to 2007, field trials were conducted before the Ajeeb-YG release, which showed resistance against three economically important maize borers, pink corn borer (*Sesamia cretica*), purple-lined corn borer (*Chilo agamemnon*) and European corn borer (*Ostrinia nubilalis*) (Karembu et al. 2009; Massoud 2010) with 30% higher yield than the traditional yellow hybrid maize. Farmers started adopting GM crops, and in 2008, a total of 700 ha of *Bt* maize was grown which increased to 2000 ha by 2010 and jumped to 100,000 ha in 2011 (Hillocks 2009; Ezezika and Daar 2012; ISAAA 2011).

iv. **Sudan:** Sudan was the fourth African country to commercialize GM crops in 2012 cultivating *Bt* cotton (ISAAA 2012). Cotton is one of the important cash crops and is a principal export commodity ((Encyclopedia of Nations: Sudan-Agriculture 2008). African bollworm (*H. armigera*) is one of the major threats to the cotton accounting 60% of the yield loss (Ahmed et al. 2002). Farmers relied heavily upon the usage of synthetic pesticides to contain this pest, which resulted in severe human health and hazardous environmental impacts (Wondafrash et al. 2012).

10.3 Genetic Tools and Techniques

Researchers across the world insistently look for novel strategies to enhance crop production and combat to meet the global food demand through food security (Muzhinji and Ntuli 2020). In pest management, involving an integrated approach will be necessary for attaining agricultural sustainability, food security as well as environmental protection. Genetically engineered (GE) crops give protection against crop insects and diseases. Crops with tolerance to herbicides are an important component in integrated pest management (Anderson et al. 2019).

Advanced genetic engineering tools for entomopathogens have been developed for managing insect viruses. Scientists recovered more than 500 baculoviral isolates from different insect species; of these, the majority are from lepidopterans (Itaya 2013). This technology depended on the promoter that drives the expression of a structural protein, polyhedron, producing large amounts during replicative cycles in viruses. The significant level of articulation from this promoter makes it alluring for developing insecticidal proteins, yet the late timing of activity confines the improvement in kill time over wild kind infections.

This leads to the belief that several other insect virus groups could also be amenable to genetic engineering techniques (Kolliopoulou et al. 2017). For example, the iridoviruses and entomopox viruses are also large and possess double-stranded

DNA and for some of them good cell culture mediums available for the commercial exploitation. Advanced genetic engineered tools are needed for exploitation towards insect management as neither of these viruses possesses targeted pathogenicity in wild forms. These genetic tools are advantageous in targeting orthopteran and dipteran species for which there are no known baculoviruses for their management. It is possible to engineer certain bacteria and transfer toxin genes from *Bt* to other bacteria with different ecological niches (e.g. cyanobacteria) and environmental stabilities (e.g. pseudomonads) (Soucy et al. 2015).

Alternatively, or in complimenting other genetic tools, biological insecticides can be developed using genetic engineering of the pathogens to increase their potential. Two classes of genes have the potential for insertion into viruses, i.e. neurotoxins and genes whose products are capable of disrupting hormonal functions. Already, neurotoxin genes have been engineered into the baculovirus from *Autographa californica*, where one encodes venom protein from scorpion and another toxin from the straw itch mite (Tomalski and Miller 1991; Stewart et al. 1991). Similarly, hormone-related genes encoding the juvenile hormone esterase (Breitenbach et al. 2011; Liu et al. 2019) and diuretic hormone (Gramkow et al. 2010; Beas-Catena et al. 2014) have already shown promising results in baculoviruses.

In Africa, countries like South Africa emphasize on the understanding of novel techniques such as ELISA, Western blotting and immunoaffinity purification (Rybicki et al. 2011). The first step in this direction was with the novel application of restriction mapping for characterizing and differentiating the dsDNA replicative intermediates of the genomes of Maize streak mastre viruses (MSV, Geminiviridae), the causative agents of the most serious virus disease of maize in Africa (Schnippenkoetter et al. 2001). Currently, the focus is on the expression of foreign proteins in plants, and the Agrobacterium tumefaciens-mediated transformation of tobacco—*Nicotiana tabacum*—with constructs derived from South African strains of tobacco necrosis (TNV) and cucumber mosaic (CMV) viruses, aimed at conferring resistance to these viruses (Hackland et al. 2000).

10.4 Advanced Genetic Tools

10.4.1 Engineered Host Resistance

For decades, classical genetic measures have been deployed towards building protection against insect pests. For plants, *Ti* plasmid from the bacterium *Agrobacterium tumefaciens* was used as the transfer vector (Klee and Rogers 1989), while the host tissues used more protoplasts. The main drawback in this technology is the small size of host ranges of *A. tumefaciens*. It does not include many economically important crops, cereals, for example, are all excluded. Recent advances in the field brought a new ‘ballistic’ technology, in which DNA is ‘shot’ into the plant cell, leading to the transformation with the *Ti* element (Klein et al. 1990) which helps in producing a transgenic plant with new desirable traits.

Many countries in Africa are geared towards developing pest-resistant crop varieties by exploiting advance genetic engineering technologies. For instance, Kenya is aiming to develop insect-resistant pigeon peas (Komen and Wafula 2013). Egypt developed virus-resistant tomato, drought- and heat-tolerant wheat, virus-resistant squash, salt-tolerant cotton, transgenic maize plants for the production of hepatitis B virus vaccine and virus-resistant potato (Abdallah 2010; Sawahel 2004). South Africa developed sugarcane with herbicide tolerance, borer pest-resistant hybrids (Meyer and Snyman 2013) as well as grapevines having viral and fungal resistance (Esterhuizen and Kreamer 2012) by utilizing GE technologies.

In West African countries, the focus has been on the development of transgenic cowpeas (Sithole-Niang et al. 2001). In cowpea, the aim was to explore advanced next-generation sequencing (NGS) and single nucleotide polymorphism (SNP) genotyping technique to understand the population genetic structure of *Maruca vitrata* (Margam et al. 2011). These studies contribute towards understanding gene flow in *M. vitrata* and assist in the enhancement of integrated pest management (IPM) programs (Agunbiade et al. 2013). Technologies like Roche 454 sequencing assist in generating and assembling contigs from DNA sequence which reads from cDNA libraries for *Anisopodus curvipes*, *A. craccivora*, *Clavigralla tomentosicollis* and *Mylothris sjostedti*. Individual gene transcript annotations were used to identify genes putatively responsible for the regulation of insect growth, insecticide resistance and response to disease transmission (Agunbiade et al. 2013).

10.4.2 Genetic Engineering of Insects

The implication of genetic engineering technologies on insect pests has three potential benefits in pest management. Firstly, the engineered pests allow for genetic control systems with chromosomal translocations. This is successfully demonstrated in the Australian sheep blowfly, *Lucilia cuprina*, for example (Whitten and Hoy 1999). Secondly, the engineered beneficial insects enhance their efficacy in managing the insect pests. For instance, engineered parasite/predators for insecticide resistance gene give promising results in pest management. Finally, a genetically engineered insect would act as a tool for understanding the functions of strategic genes in insects with economic significance. For example, the characterization of genes responsible for insecticide resistance would assist the management and monitoring resistance for current insecticides as well as aid in designing new insecticides or synergists that successfully break the resistance cycle.

10.4.3 Sterile Insect Technology (SIT)

SIT technique involves mass-rearing of the target species, followed by sterilizing them with ionizing radiation, and finally releasing the sterilized insects into the target area in large quantities every week (Klassen 2005). These released sterilized males mate with fertile ‘wild-type’ females, resulting in infertile eggs and systematic reduction of the size of successive generations (Barnes et al. 2004; Conlong and Rutherford 2009).

The Sterile Insect Technology (SIT) programme in South Africa was initiated in 1996 to combat Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann). In 1997, the Agricultural Research Council initiates SIT pilot programmes in South Africa. Sterile Insect Technology was attempted against false codling moth (*Thaumatotibia leucotreta* (Meyrick)) on citrus and codling moth (*Cydia pomonella* (Linnaeus)) on apples and pears. Later SIT programme was developed for the sugarcane stalk borers, *Eldana saccharina* Walker and *Chilo sacchariphagus* Bojer (Potgieter et al. 2013). Ghana and Mauritius are also implementing SIT techniques for the management of fruit flies (Seewooruthun et al. 2000; Permalloo et al. 2005; Ogaugwu et al. 2012).

10.4.4 CRISPR

The adoption of modern technologies such as clustered regularly interspaced short palindromic repeats (CRISPR, as known as CRISPR-Cas9) is much needed to reduce the usage of synthetic pesticide and herbicides (Pretty and Bharucha 2015; Schinasi and Leon 2014). CRISPR genetically edits organisms which do not have transgenic footprints. This is because it delivers preassembled Cas9-sgRNA ribonucleoproteins or by transient expression of in vitro transcripts of the Cas9 coding sequence and sgRNA. By using CRISPR-based gene drive systems, it is possible to reverse pesticide resistance in insects (Esvelt et al. 2014). In African countries, farmers depend on host-resistant varieties to reduce pesticide use in their fields (Nekrasov et al. 2017; Malnoy et al. 2016; Wang et al. 2016); now, using CRISPR/Cas9 system, it is possible to understand the gene functions in plants (Ma et al. 2015) which facilitates the manipulation of wild relatives of cultivated crops against invasive pests and weeds. Thus, CRISPR technology is comparatively cheap and has the potential to improve food security and enhance nutrition in Africa.

10.4.5 RNA Interference (RNAi)

Since the discovery of the RNAi technique in 1998 (Fire et al. 1998), it has become an important tool for managing insect pests and understanding the gene functions in a non-model organism. RNAi is a collection of several biological processes utilizing conserved cellular machinery to silence the expression of certain genes in the organism (Hannon 2002; Mello and Conte 2004). Ingestion of RNAi by the insect is a major challenge, and scientists use the indirect route, through their prey or hosts to ingest it. Herbivores during their feeding activity ingest the dsRNA through the treated plants. Ingested dsRNA remains biologically active when passed on to the next trophic level (Romeis and Widmer 2020). Arthropods display a wide range of sensitivities to ingested dsRNA (Bellés 2010). Insects belonging to order Coleoptera show greater sensitivity to RNAi than other orders (Christiaens et al. 2016), with an

LC50 at dsRNA concentrations from 1 to −10 ppb (Baum and Roberts 2014). Lepidoptera showed variable susceptibility to ingested dsRNA with high concentration requirements to elicit a response (Terenius et al. 2011; Ivashuta et al. 2015).

10.5 Biosafety Policies in Africa

In 1992, the UN emphasized the eco-friendly management of modern biotechnology, and the Convention on Biological Diversity (CBD) and safety guidelines for GMOs were published (Codex Alimentarius 2003; Haslberger 2003; Ladics 2008). In 1995, the World Trade Organization-Technical Barrier to Trade (WTO-TBT) put forth guidelines towards GMO regulations. The Cartagena Protocol (Protocol 2000) on biosafety aims for regulating the safe transfer and handling of GMOs as well as protecting biodiversity (Alexandrova et al. 2005; MacKenzie 2000). In 1962, an international governing body of the FAO, the Codex Alimentarius Commission (CAC) and the WHO jointly established promulgated the Codex guidelines (Alimentarius 2003) for the food safety assessment and evaluation of the immunogenic potency of GMOs.

South Africa started adopting biotechnology at an early stage. The first field trials of genetically modified crops were conducted in 1989/1990 (Wolson 2007). For the first time in 1997, South Africa approved the commercial release of genetically modified, insect-resistant cotton and maize (Dirk 2019). South Africa started with GM maize in 1996, then cotton in 1997 and soybean in 2001. Now, South Africa is the eighth largest producer of GMO crops in the world. Making it Africa's only "mega-biotech country" (https://www.africabio.com/agriculture) with a total of 2.73 million ha dedicated to the planting of GMO crops (Agaba 2019). In the meantime, the rest of African countries delayed proceeding with the development in the field of biotechnology and genetic engineering, especially after a resurgence of activism against GMOs (Fig. 10.6). In South Africa, Genetically Modified Organisms Act of 1997 (GMO Act) and its subsidiary legislation govern the use, trial release, commercial release and import and export of genetically modified organisms with several restrictions on the research, production and marketing of GMOs. The GMO Act was amended in 2006 (although the amendment did not take effect until 2010) in part to give effect to the Cartagena Protocol on Biosafety, which South Africa ratified in 2003 (GMO 2006). There are also several other laws imposing additional laws on GMO-related activities, including the National Environmental Management: Biodiversity Act (NEM: BA 2004), the Consumer Protection Act (CPA 2008) and the (FCD 1972).

10.6 Challenges in Adoption and Use of Genetic Tools

The key factors hampering using these advanced genetic engineer technologies in African countries include lack of infrastructure, inadequate capacity and operational support and lack of statutory and regulatory framework and enabling policy (see

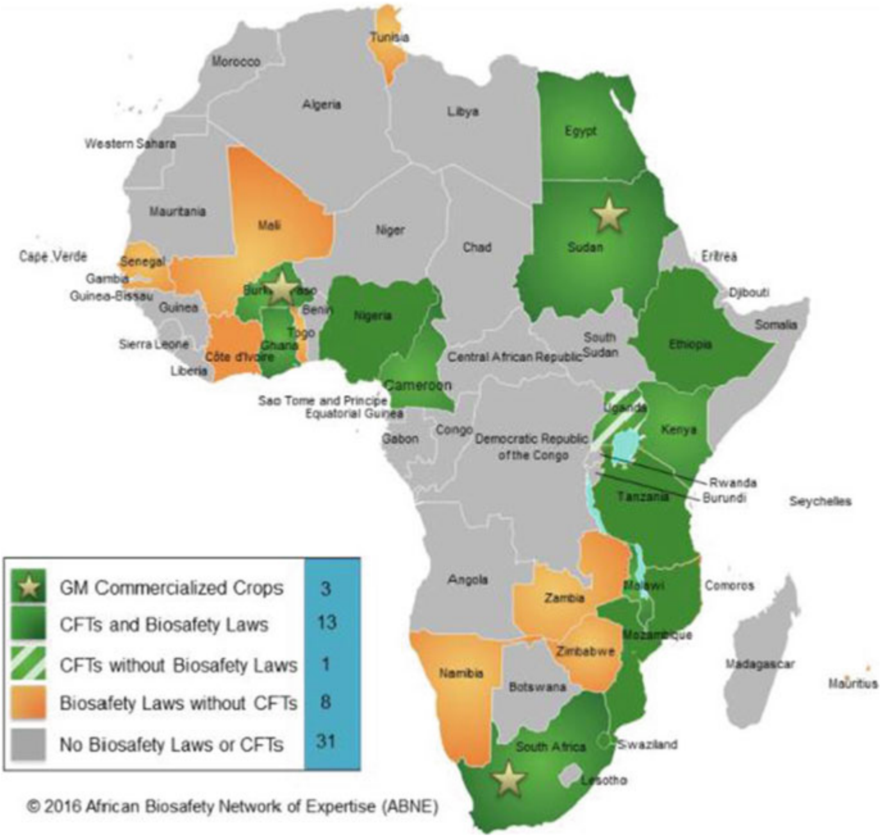

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Fig. 10.6 Status of biosafety legislation across African countries (Source: http://africenter.isaaa.org/status-of-biosafety-legislation-in-africa/)

above section), which in turn affect operations of research institutions (Ribaut et al. 2010). In May 2015, people and activists from South Africa protested against the use of Monsanto's GM foods, stating it will lead to serious health conditions such as the development of cancer tumours, infertility and birth defects (https://www.bizcommunity.com/Article/196/642/129091.html). In November 2019, South African Agriculture Minister rejected Monsanto's request for the commercial cultivation of its allegedly drought-tolerant, insect-resistant MON87460 × MON89034 × NK603 maize seed in the country (https://www.slowfood.com/south-africas-agriculture-minister-rejects-monsatos-gm-maize-seed/). This indicates unequal levels of trust of the safe application of GMOs. These are just some of the examples were activist groups/civil society have managed to engage government on the GMO approval processes in South Africa. It is worth noting that nonprofit organizations (NPOs) such as the African Centre for Biodiversity (ACB) continue to play an important oversight role, acting as a watchdog on GMO activities in South Africa. According to their website https://www.acbio.org.za, ACB is a research and advocacy organization, acting in the public interest, and has played a historical role in regulatory oversight and decision-making processes on biosafety, particularly in light of biodiversity, agricultural biodiversity, environmental and socio-economic impacts. Several reports regarding their interaction, petitions (https://www.acbio.org.za/en/petitions), appeals and communique with the SA government on GMO matters can be accessed via their website.

These advanced new technologies, particularly genetic engineering, come with the high cost and intellectual property protection. This creates the largest profit for the biotech companies, and cost associated with this may spill over into product prices that outpace the particularly resource-poor farmers in Africa (ASSAF 2010; Adenle 2011). According to Kalaitzandonakes et al. (2007), approximately US $7 million to US$15 million will cost for regulatory compliance for Bt maize apart from its developmental costs.

The major challenge to genetic engineer for pest protection into plants is the shortage of cloned insecticidal genes (Al-Aboodi and Ffrench-Constant 2017). These genes must encode insecticidal proteins that need to be orally active, but for most insects, this means that they must disrupt the function of their digestive tract. At present, the only group of genes meets these criteria, i.e. *Bt* delta endotoxins. But their toxicity is too low for use in genetic engineering programmes for the pest-resistant animals. This shows the urgent need for *Bt* alternatives both in the event of resistance development by the insect pests and contains the pests that are not susceptible to Bt (Gassmann et al. 2011).

Ethiopian people raised their voices regarding socioeconomic concerns, like GMO's incompatibility with Ethiopian farming systems dominated by poor farmers' with small landholdings dependence on multinational companies for expensive and patented seeds (Abraham 2014). In Ethiopia, people are highlighting the possible negative effect of GM food products on human health.

10.7 Conclusion

There are promising projects currently underway in African countries to develop crops that will enhance their quality and resilience against various threats, pests and pathogens. This is an indication that agriculture crops stand to benefit from modern genetic engineering technologies. At the same time, there is still a strong need for decisive action and commitment from various African governments towards exploiting the potential of biotechnology and genetic advancements. This is because these technologies present a good opportunity for enhancing agricultural productivity and sustainability. Research has already highlighted the diverse potential of these technologies, even for the benefit of biodiversity, the environment and human health. Further knowledge and skills development might be necessary for some areas to ensure adequate administration, management and safe use of the various technological advancements. African countries will also need to ensure that they own rights to these technologies as this allows for easy access and affordability to the different products derived from the technological advancements.

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