3.5 Developing and deploying climate-smart maize and pod borer resistant cowpea for smallholder farmers in Africa

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Abstract

Frequent droughts and outbreaks of insect pests are significant constraints to the gainful production of the major staple crops, maize and cowpea in sub-Saharan Africa. The routine access to agricultural biotechnologies, which could address these constraints, is limited in the region. In this case study, we describe the brokered royalty-free access to proprietary biotechnologies and their subsequent use in the genetic improvement of these two food security crops. Modern plant breeding techniques, including doubled haploidy and molecular marker-assisted breeding, were used to develop over 120 conventionally bred climate-smart DroughtTEGO® maize hybrids, which were released mostly in East and Southern Africa. Transgenic TELA® maize hybrids that were resistant to fall armyworm, stem borers and drought were also developed in Ethiopia, Kenya, Mozambique, Nigeria and South Africa. Additionally, transgenic cowpea varieties with resistance to pod borer insects were developed; the SAMPEA 20-T variety was released in Nigeria. All these improved varieties had significantly higher yields than the commercial check varieties, especially under the target stress conditions. The adoption of the insect-resistant varieties led to significant reductions in the use of expensive and harmful insecticides. Overall, there were significant improvements to the livelihoods of farmers, typically smallholders, who adopted these improved crop varieties. Partnerships, especially between the public and private sectors, sustained funding and political goodwill were critical to the successful development and deployment of these solutions.

Introduction

Maize (*Zea mays* L.) is an important food security crop for over 300 million people in sub-Saharan Africa (SSA). The frequent incidents of drought and damage by insect pests, especially stem borers (*Chilo partellus*, *Busseola fusca* and *Sesamia calamistis*) and, most recently, fall armyworm (FAW, *Spodoptera frugiperda*), which are associated with climate change, pose significant threats to the production of the crop. On average, drought causes a yield loss of about 17 percent for maize in the region. Compounding this, stem borers infestation reduces maize production by an average of 13 percent or 400 000 tonnes of maize per year, for instance in Kenya. This is equivalent to the country's annual import of the crop, valued at over USD 90 million (De Groote, 2002). First observed in the continent in 2016, FAW, a devastating and transboundary pest, if not controlled adequately, could cause yield losses of up to 20 million tonnes of maize annually, which is enough to feed 100 million people (CABI, 2017).

Cowpea (*Vigna unguiculata* [L] Walp.), commonly known as black-eyed pea, is also a staple crop for over 200 million households in SSA (Kamara *et al.*, 2016). The crop's protein-rich grains, green leaves and immature pods are all eaten, with the grains being used as important weaning food for babies (Bassey *et al.*, 2013). Pod borer (*Maruca vitrata* F) is one of the major insect pests of the crop, with its infestation causing significant yield losses of 20 to 80 percent (Addae *et al.*, 2020). With no known varieties that are resistant to *M. vitrata,* smallholder farmers, the main producers of the crop, spray their farms several times each season with expensive synthetic insecticides (Murdock *et al.*, 2008) which, in addition to being detrimental to the environment and human health, are usually ineffective against the insect's larvae (Ba *et al.*, 2019).

In 2004, the African Agricultural Technology Foundation (AATF), with headquarters in Nairobi, Kenya, brokered access to a royalty-free license from Bayer (then Monsanto Company) to use its proprietary technologies for the genetic improvement of these food security crops in SSA. These were the Cry series of genes, Cry1Ab and Cry1A.105/Cry2Ab2, isolated from the bacterium *Bacillus thuringiensis* (Bt); and the CspB gene, a cold shock protein isolated from the bacterium *Bacillus subtilis*. The innovative use of genetic engineering or genetic modification, based on these genes, and molecular breeding approaches to develop varieties of these two food security crops, which are resistant to these production constraints, is described in this case study.

Climate-smart maize: Product development, commercialization and impacts

Product development

The aim of the Water Efficient Maize for Africa (WEMA) Programme, which commenced in 2008 and was renamed the TELA Maize Programme in 2018, was to develop and deploy new climate-smart maize hybrids for smallholder farmers that would be both drought-tolerant and insect-resistant through an innovative public-private partnership (PPP) (Oikeh *et al.*, 2015). The partners and their contributions are summarized in Table 1. Anchored by the guiding principle that the products of biotechnology are safe and could contribute to enhanced food security and nutrition, the partnership benefits from long-term investments by the Bill and Melinda Gates Foundation (BMGF), the Howard G. Buffett Foundation (HGBF) and the United States International Development Agency (USAID).

The climate-smart varieties were developed using both non-transgenic breeding and transgenic techniques. For the former, doubled haploidy, i.e., the chromosome doubling of haploid cells was used to develop homozygous breeding lines in one generation (compared with up to six generations through selfing). The molecular marker-assisted breeding (MAB) techniques, marker-assisted recurrent selection (MARS) and genome-wide selection (GWS), were used to further increase the efficacy and speed for breeding the improved varieties (Spindel *et al.*, 2015). Definitions of these and other main biotechnologies described in this case study are provided in Box 1.

For the genetic engineering techniques, the *CspB* gene, which confers drought tolerance, was used to transform maize, with the resulting transformation event and trade name being MON87460 and DroughtGard® respectively. Similarly, the resulting transformation events using the insect resistance genes *Cry1Ab* and *Cry1A.105/Cry2Ab2* were Bt MON810 and MON89034 respectively. These conferred resistance to FAW and stem borer in already adapted conventionally bred drought-

Box 1. Definitions of technical plant breeding terms

Doubled haploids (DH) technology: Doubled haploid (DH) technology is used in plant breeding to rapidly develop true breeding plant lines by chromosome doubling of haploid cells. Haploid cells contain a single set of chromosomes. Haploid cells are produced from pollen (male) or egg (female) gametes or plant sex cells. Doubled haploids (DH) are produced when the haploid cells undergo either induced or spontaneous chromosome doubling. The doubled haploid cell can then be grown into a doubled haploid plant. Conventional inbreeding procedures take six generations to achieve approximately complete homozygosity (the presence of two identical alleles at a particular gene locus) or true breeding status, whereas doubled haploidy achieves it in one generation.

Molecular markers-assisted breeding (MAB): Classical plant breeding is the intentional interbreeding and selection of plant varieties with the goal of producing new varieties with improved properties. Marker-assisted breeding (MAB), more precisely molecular markers-assisted breeding, combines classical plant breeding with the tools and discoveries of molecular biology and genetics, most specifically the use of molecular markers. Molecular markers are variants in the DNA sequence which acts as an identifier or tag of a particular aspect of phenotype and/or genotype and its inheritance can easily be followed from generation to generation.

Marker-assisted recurrent selection (MARS): Marker-assisted recurrent selection (MARS) is a breeding method used to accumulate favourable alleles within a single population. In MARS, marker-assisted selection is used for three or more cycles in a plant population to improve traits governed by more than two genes as a means of increasing the frequency of the desirable genes for various economic characters. It helps in maintaining the high genetic variability in the heterozygous population and increases the efficiency and effectiveness of the population improvement by avoiding the influences of environmental effects.

Genome-wide selection (GWS): Genome is the complete set of DNA (genetic material) in an organism. The genome contains all the information needed for the organism to develop and grow. Genomic selection involves making use of the estimated association between many markers and the phenotype to estimate the breeding value of the plant without phenotype. A genome-wide association study (GWAS) is a research approach used to identify genomic variants that are statistically associated with a particular trait. GWAS explores the complete genome, in contrast to other approaches that exactly investigate a minor amount of pre-specified chromosomal areas. Genomic selection is a form of marker-assisted selection in which genetic markers covering the whole genome are used so that all quantitative trait loci (QTL) are in linkage disequilibrium with at least one marker. Genome-wide selection, therefore, is based on all the good genetic make-up of a plant for a particular trait.

Genetic engineering: Genetic engineering (also called genetic modification) is a process that uses laboratory-based technologies to alter the DNA makeup of an organism. This may involve changing a single base pair (A-T or C-G), deleting a region of DNA, or adding a new segment of DNA. For example, genetic engineering may involve adding a gene from one species to an organism from a different species to produce a desired trait. Used in research and industry, genetic engineering has been applied to the production of genetically modified plants.

Source: Dr Stephen Mugo, Independent Consultant Breeder, TELA Maize Programme Advisor, Personal Communication, 2022.

Table 1. Partners and their contributions to the WEMA/TELA Maize Programme

Organization	Contribution
AATF	● Overall coordination of the PPP ● Brokerage of royalty-free licensing ● Product deployment and stewardship ● Communication, outreach and advocacy ● In-country regulatory approvals and compliance ● Monitoring and evaluation
International Maize and Wheat Improvement Center (CIMMYT)	● Provision of crop germplasm adapted to SSA ● Conventional breeding, including the use of marker-aided selection and doubled haploidy, for tolerance to biotic and abiotic stresses ● Field testing, including for regional trials
Bayer Crop Science	● Provision of the genes Cry1Ab and Cry1A.105/Cry2Ab2 for insect resistance and CspB for drought tolerance, royalty free ● Provision of crop germplasm adapted to different regions of the world ● Conventional breeding, including the use of marker-aided selection and doubled haploidy, and genetic engineering for tolerance to biotic and abiotic stresses ● Biotechnology testing and stewardship ● Seed production, deployment and licensing ● Regulatory data packages
National agricultural research system (NARS) of: ● Ethiopia ● Kenya ● Mozambique ● Nigeria ● South Africa ● Uganda ● United Republic of Tanzania	● Provision of locally adapted germplasm ● Conventional breeding for tolerance to biotic and abiotic stresses ● Field testing, including for regional trials ● Knowledge of farmers' product needs

tolerant varieties. The inclusion of the drought tolerance gene further enhanced yield under drought stress conditions by at least 10 percent (Castiglioni *et al.*, 2008). Bayer conducted the genetic transformation in its facilities in Mexico.

Subsequently, Bayer South Africa and the Agricultural Research Council (ARC), the South African NARS, crossed the drought-tolerant and insect-resistant transgenic variants with elite maize parental lines. The promising maize varieties with the incorporated transformation events were further trialled in the seven programme countries (Table 1) in collaboration with the respective NARS and other programme partners.

The 124 hybrid maize varieties developed through non-transgenic breeding and released to farmers were trademarked DroughtTEGO® (TEGO means shield in Latin). The transgenic varieties, developed with Bt only or Bt stacked with drought tolerance traits, were called TELA® (from the Latin word *Tutela*, meaning protection). A mean genetic gain of 70.5 kg per hectare per year, which was obtained for DroughtTEGO® hybrids from using GWS, was two to four times higher than those ever reported from conventional or non-transgenic breeding in SSA (Beyene *et al.*, 2015).

A farmer in Kitali, Kenya, in October 2018 identifies the non-transgenic DroughtTEGO® WE6105 hybrid as the best performing DroughtTEGO® hybrid in her demonstration plots for the Highlands agroecology in western Kenya

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Relative to isogenic conventionally bred hybrids, under combined FAW and stem borer infestation, on average, TELA® hybrids with Bt MON810 had 43 percent yield advantage while, under moderate drought-stress, TELA® with MON87460 trait gave about 17 percent yield advantage. But under optimum moisture conditions with chemical control of pests, TELA® hybrids produced similar yield as conventional isogenic hybrids, confirming that there were no unintended changes due to genetic transformation. These promising results strengthened the applications for the environmental release of the transgenic insect-resistant and drought-tolerant events in Ethiopia, Kenya, Mozambique, Nigeria and South Africa.

In Makhatini, South Africa, Dr Kingstone Mashingaidze, a maize breeder from the Agricultural Research Council, showcases in October 2019 the performance of the TELA® WE6208B Bt hybrid (right) vs. the non-transgenic, drought tolerant, DroughtTEGO® WE3128 hybrid (left) under combined moderate drought and severe fall armyworm and stem borer infestation. The WE6208B hybrid had a six-fold higher yield than the WE3128 hybrid

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Product deployment and commercialization

Since 2016, five TELA® maize varieties have been commercialized in South Africa, where they have been adopted by smallholder farmers. These varieties are contributing significantly to the management of FAW in the country. At the time of preparing this article (November 2022), the approval processes for the commercialization of three TELA® maize varieties were ongoing in Kenya, while promising results have been obtained for 12 varieties, which are undergoing variety certification trials in Nigeria.

To get the improved maize varieties to farmers, AATF followed a business model which was used first for the commercialization of DroughtTEGO® maize varieties in Kenya in 2013. The model involves, among other components: the establishment of demonstration plots for farmer participatory variety selection; issuing humanitarian-use licenses for the varieties to small- and medium-enterprise (SME) seed companies; and establishing linkages with early generation seed suppliers such as two AATF's subsidiaries, QulaiBasic and EcoBasic seed companies for the production of foundation seeds. The business model also includes developing an account management system, involving technical backstopping on seed production and business support for licensed SME seed companies. The provision of stewardship support, involving the preservation of product integrity by adopting standard operating procedures, quality control and assurance, and insect resistance management to delay the development of resistance by the target pests, is also an integral part of the business model.

Within five growing seasons, in less than three years, over 4860 demonstration plots were established across 17 counties in Kenya. The yields of DroughtTEGO® varieties, which ranged from 5.5 to 6.3 tonnes per hectare, were 33 to 54 percent higher than those of the commercial check varieties (Obunyali *et al.*, 2019). The experience and lessons learned were used in the release of the varieties in other non-programme countries, Benin, Cameroon, Ghana, Rwanda, Zambia and Zimbabwe, in particular through the Technologies for African Agricultural Transformation (TAAT) programme funded for three years by the African Development Bank.

Impacts of DroughtTEGO® and TELA® Maize

The issuance of humanitarian-use licenses to 38 SME seed companies to commercialize DroughtTEGO® and TELA® varieties was one of the key success factors for impact. Through the account management system that was put in place, the annual volumes of certified seeds that were produced by licensed SME seed companies were tracked. It was estimated that between 2013 and 2020, over one million hectares were sown with over 29 000 tons of certified seeds of these improved maize varieties in 13 countries, Benin, Cameroon, Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Rwanda, South Africa, the United Republic of Tanzania, Uganda, Zambia and Zimbabwe (Table 2).

Table 2. The volume of seeds (tonnes) of the DroughtTEGO® (non-transgenic drought tolerant) and TELA® (transgenic drought tolerant and/or insect resistant) maize varieties produced by SME seed companies on the strength of humanitarian-use licenses issued by AATF in 13 countries from 2013 to 2020 through the WEMA/TELA or the TAAT programme

Year	Volume of seeds produced by programme/product			
	WEMA/ DroughtTEGO®	TELA/TELA®	TAAT/ DroughtTEGO®	TOTAL
2013	75	-	-	75
2014	217	-	-	217
2015	1 986	-	-	1 986
2016	1 998	5	-	2 003
2017	947	56	-	1 003
2018	533	97	930	1 560
2019	685	28	21 031	21 744
2020	591	5	22	618
TOTAL	7 032	191	21 983	29 206

Source: AATF Deployment and Commercialization Database, 2021.

In 2021, AATF commissioned an external impact evaluation of the WEMA programme in Kenya, the United Republic of Tanzania and Uganda. It was shown that the productivity of maize and the consequent income generation for farmers increased significantly with the adoption of these new varieties. In Kenya and Uganda, for instance, the cultivation of DroughtTEGO® led to an average yield increase of 248 percent while income generation was enhanced by 84 percent (AATF, 2021). The hybrids were recently described as 'magic seeds' (BMGF, 2022) because they were already enhancing the livelihoods of farmers in both countries. These significant improvements were not observed in these two indicators in the United Republic of Tanzania, possibly because deployment started very late in this country, a couple of years before the closure of the WEMA programme in 2018.

Pod borer resistant cowpea: Product development, commercialization and impacts

Product development

Enabled by funding from the USAID and the Rockefeller Foundation, a PPP was formed to facilitate the use of the Cry1Ab gene to develop pod borer resistant (PBR) cowpea varieties for deployment to smallholder farmers (Table 3).

The Cry1Ab gene was used to transform the cowpea variety IT86D-1010 in CSIRO where the efficacy against the *Maruca* pest was demonstrated (Higgins *et al.*, 2012). Subsequently, several variants with the incorporated Cry1Ab-expressing events were tested in a confined environment under severe *Maruca* artificial infestation in Nigeria, Burkina Faso and Ghana. Scientists at the NARS in Nigeria, Burkina Faso and Ghana used a variant known as Event 709A, identified as the most promising, as the parental line to introgress the insect resistance trait into farmer-preferred varieties.

The resulting transgenic PBR cowpea varieties were evaluated in confined field trials from 2011 to 2016 in the three countries (Addae *et al.*, 2020). The confined field trials results showed consistently that there was nearly a complete protection from *Maruca* for the pods and seeds of transgenic cowpea varieties. In most cases. there were also significant increases in grain yield over non-Bt control lines. Also, with the transgenic varieties, the frequency of the spraying of insecticides to control the pests was reduced from six to ten times per season to just two, representing a saving of four litres of insecticide per hectare or USD 12.5 per hectare.

In Nigeria, after the approval by the National Biosafety Management Agency for commercial release in January 2019, followed by successful variety certification trials across cowpea growing agroecologies, the first PBR cowpea variety, known as SAMPEA 20-T, was registered and released for cultivation in December 2019 (Addae *et al.*, 2020). Transgenic PBR cowpea was also approved for environmental release towards commercialization in Ghana in June 2022 by the National Biosafety Authority following which national multi-locational performance trials for the registration and release of the promising varieties were commenced. In Burkina Faso, it was envisaged that the regulatory dossier for its environmental release would be submitted to the biosafety regulatory authority for review and decision making in December 2022.

Table 3. PBR cowpea project partners and roles in product development and deployment

Organization	Roles
AATF	AATF coordinated and managed the PPP; brokered royalty-free access to the proprietary Bt technology and the ensuing varieties; provided expertise and support in product development, regulatory compliance, business development, seed delivery and stewardship, communication and outreach.
Bayer Crop Science (then Monsanto Company)	Donated the proprietary biotechnology, i.e. the Bt gene construct, used for cowpea transformation on a royalty-free basis
Purdue University, through the Network for Genetic Improvement of Cowpea for Africa (NGICA)	Provided technical backstopping to the project at product development phase
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	Responsible for the genetic transformation of cowpea and the generation of the variants for field testing
Donald Danforth Plant Science Center	Supported the development of the regulatory dossier for commercial approval of PBR cowpea in project countries
Institute of Agricultural Research, Ahmadu Bello University, Samaru, Nigeria	Conducted field testing and variety development in Nigeria
Council for Scientific and Industrial Research – Savana Research Institute, Ghana	Conducted field testing and variety development in Ghana
Institute de l'Environnement et de la Recherche Agricole, Burkina Faso	Conducted field testing and variety development in Burkina Faso
International Food Policy Research Institute, Program for Biosafety Systems	Supported regulatory compliance training in project countries

Product deployment and commercialization

When the SAMPEA 20-T cowpea variety was launched in Nigeria in 2021 by AATF, in collaboration with the Institute of Agricultural Research, Samaru, Nigeria and other Nigerian government agencies such as the National Agricultural Seed Council, a similar business model as described for maize earlier was also followed. In the first year of commercialization, smallholder farmers planted 7 tonnes of the seeds. The seed delivery system involved the issuance of humanitarian-use licenses for the SAMPEA 20-T variety to three SME seed companies and the establishment of product stewardship, and a seed systems advisory package to support the seed and crop production process. An insect resistance management plan for Bt cowpea which required non-Bt cowpea refuge fields to be planted in proximity to the Bt cowpea fields was recommended. The aim was to provide sources of susceptible insects from the non-Bt refuge fields, which can breed with insects that may survive exposure to the Bt protein, thus delaying the development of insect pest resistance to the Bt protein. A community or village refuge insect resistance management approach was implemented, whereby non-Bt cowpeas and landraces planted by neighbouring farmers provided sources of

Mr Bernard Ehirim, African Agricultural Technology Foundation, inspects the performance of pod borer resistant SAMPEA 20-T cowpea seed production in Philip Ibrahim's farm in Mokwa, Niger State, Nigeria in November 2022. The field was completely free of pod borers and good harvest was assured

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insect pests (*M. vitrata),* which were susceptible to Cry1Ab protein, in order to prevent the evolution of resistant biotypes.

More recently, additional funding was provided by the BMGF for the out-scaling of the commercialized transgenic variety in Nigeria in response to the bourgeoning demand by smallholder farmers.

Potential impacts of PBR cowpea

Ex ante impact assessment using an economic surplus partial equilibrium model estimated a total net present value (NPV) of adopting PBR cowpea varieties that ranges from USD 5.6 million to USD 125.4 million over a 30-year period in Ghana (Dzanku *et al.*, 2018). The net present value benefits of adopting PBR cowpea for producers and consumers were estimated at about USD 350 million, with 70 percent accrued by producers over a period of 25 to 35 years in Nigeria (Dayo *et al.*, 2019).

Major challenges in developing climate-smart maize and PBR cowpea

The key challenges encountered in developing these new varieties included the replication of managed drought stress assays in confined field trials across countries in formats that were suitable for data transferability. Secondly, in some countries, there were prolonged delays in getting government approvals for environmental release of the transgenic varieties, which was needed for variety certification trials and ultimately obtaining approval to commercialize them. Finally, there has been increased anti-biotech activism in Africa aimed at preventing African farmers from adopting transgenic crop varieties.

Lessons learned in developing climate-smart maize and PBR cowpea

The use of a PPP model for product development and deployment enabled access to critically important proprietary biotechnological tools and expertise as well as diverse elite germplasm from public and private partners, which otherwise would not have been available to a single partner organization.

The holding of licensee SME seed companies accountable for attaining high seed quality standards through humanitarian-use licenses and account management systems and detailed stewardship measures, with compliance audits among farmers, were effective ways to enhance the efficiency of product deployment and ensure its sustainability.

The securing of the approval for general releases of transgenic crops in Africa is difficult and complicated, but not impossible if the requisite legal and regulatory framework is accompanied by consistent and supportive political goodwill.

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