GM AGRICULTURAL TECHNOLOGIES FOR AFRICA

A State of Affairs

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ABBREVIATIONS AND ACRONYMS

AATF	African Agricultural Technology Foundation
ABBPP	African Biotechnology and Biosafety Policy Platform
ABNE	African Biosafety Network of Expertise
ABS	African Biofortified Sorghum; also access and benefit sharing
ABSF	African Biotechnology Stakeholders Forum
ACIAR	Australian Centre for International Agriculture Research
ACTESA	Alliance for Commodity Trade in Eastern and Southern Africa
AfDB	African Development Bank
Africa Harvest	Africa Harvest Biotech Foundation International
African Model Law	African Model Law on Safety in Biotechnology
AFSTA	African Seed Trade Association
agbiotech	agricultural biotechnology
AGERI	Agricultural Genetic Engineering Research Institute
AGRA	Alliance for a Green Revolution in Africa
AP	agronomic property
ARC	Agricultural Research Council
ARC-VOPI	Agricultural Research Council–Vegetable and Ornamental Plant Institute
ARI	agricultural research institute
ARIPO	African Regional Industrial Property Organization
ASA	African Science Academies
ASARECA	Association for Strengthening Agricultural Research for Eastern and Central Africa
ASCU	Agricultural Sector Coordinating Unit
ASIESA	Alliance for the Seed Industry in Eastern and Southern Africa
ASTI	Agriculture Science and Technology Indicators
AU	African Union
AusAID	Australian Agency for International Development
AWARD	African Women in Agricultural Research and Development
BC Plus	BioCassava Plus
BecA	Biosciences eastern and central Africa
BIC	Biotechnology Information Center
BioAWARE	National Biotechnology Awareness Creation Strategy
BIO-EARN	Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety, and Biotechnology Policy Development

BioEROC	Biotechnology-Ecology Research and Outreach Consortium
Bio-Innovate	Bio-resource Innovations Network for Eastern Africa Development
BMGF	Bill and Melinda Gates Foundation
BNARI	Biotechnology and Nuclear Agriculture Research Institute
BR	Basta-resistant (Basta is an herbicide)
BREAD	Basic Research to Enable Agricultural Development
BRIC	biotech regional innovation center
BSL-2	biosafety level 2
BSL-3	biosafety level 3
Bt	*Bacillus thuringiensis*
BTA	Biotechnology Trust Africa
CBD	Convention on Biological Diversity
CEBIB	Center for Biotechnology and Bioinformatics
CFT	confined field trial
CGIAR	Formerly an acronym for the Consultative Group on International Agricultural Research; now simply CGIAR
CIAT	International Center for Tropical Agriculture
CIDA	Canadian International Development Agency
CILSS	Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Centre
CIRDES	Centre International de Recherche-Développement sur l'Elevage en Zone Subhumide
CMD	cassava mosaic disease
COMESA	Common Market for Eastern and Southern Africa
CORAF	Conference of African and French Leaders of Agricultural Research Institutes
COSTECH	Commission for Science and Technology
CPA	Consolidated Plan of Action
CPB	Cartagena Protocol on Biosafety
CRI	Cooperative Resources International
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CVL	Central Veterinary Laboratory
DDPSC	Donald Danforth Plant Science Center
DFID	Department for International Development (UK)
DGIS	Dutch Government Ministry of International Development and Cooperation

DNA	deoxyribonucleic acid
EAAPP	East Africa Agriculture Productivity Program
EBIC	Egypt Biotechnology Information Center
EC	European Commission
ECABIC	East and Central Africa Biotechnology Information Center
ECOWAS	Economic Community of West African States
EIAR	Ethiopian Institute of Agricultural Research
EMBRAPA	Brazilian Agriculture Research Corporation
EPO	European Patent Office
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
FARC	Food and Agriculture Research Council
FFP	food, feed, or for processing
FOCAC	Forum on China-Africa Cooperation
FPS	Furman, Porter, and Stern
FSTP	Food Security Thematic Programme
FTF	Feed the Future
G8	Group of Eight
GAFSP	Global Agriculture and Food Security Program
GDP	gross domestic product
GIIBS	Inter-Institutional Biosafety Group
GIPB	Global Partnership Initiative for Plant Breeding Capacity Building
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GM	genetic modification; genetically modified
GMOs	genetically modified organisms
GNI	gross national income
GRIP	Genetic Resources and Intellectual Property Rights
GRFA	genetic resources for food and agriculture
GURTs	genetic use restriction technologies
HT	herbicide-tolerant; herbicide tolerance
IAR	Institute of Agricultural Research (Zaria, Nigeria)
IBC	institutional biosafety committee
ICARDA	International Centre for Agricultural Research in Dry Areas
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICIPE	International Center of Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IIAM	Instituto de Investigação Agrária de Moçambique

IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IMAS	Improved Maize for African Soils
IMF	International Monetary Fund
INERA	Institut National de l'Environnement et des Recherches Agricoles
INSAH	Institut du Sahel
IP	intellectual property
IPR	intellectual property rights
IR	insect-resistant; insect resistance
IRMA	Insect-Resistant Maize for Africa
IRRI	International Rice Research Institute
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ISRA	Institut sénégalais de recherches agricoles
JPO	Japanese Patent Office
JT	Japan Tobacco
KARI	Kenya Agricultural Research Institute
KEPHIS	Kenya Plant Health Inspectorate Services
KIRD	Kenyan Industrial Research and Development Institute
LDC	least-developed country
LLP	low-level presence
LMO	living modified organism
MABI	Mauritius Agricultural Biotechnology Institute
MAFTNR	Ministry of Agriculture, Food Technology, and Natural Resources
MALR	Ministry of Agriculture and Land Reclamation
MO	modified organism
MSIRI	Mauritius Sugar Industry Research Institute
MSTD	Ministry of Science and Technology Development
MSU	Michigan State University
NABNet	Northern African Biosciences Network
NARO	National Agricultural Research Organisation
NARSs	National Agricultural Research Systems
NBA	National Biosafety Authority
NBC	National Biosafety Committee
NBF	national biosafety framework
NBRC	National Biosafety Regulatory Committee
NCST	National Commission for Science and Technology
NE	nutritional enhancement
NEPAD	New Partnership for Africa's Development

NERICA	New Rice for Africa
NEWEST	Nitrogen Use Efficient, Water Use Efficient, and Salt Tolerant
NGICA	Network for the Genetic Improvement of Cowpea for Africa
NGO	nongovernmental organization
NISIR	National Institute for Scientific and Industrial Research
NRC	National Research Center
NRCRI	National Root Crops Research Institute
NRM	natural resource management
OAPI	African Intellectual Property Organization
OAU	Organization for African Unity
OFAB	Open Forum on Agricultural Biotechnology
OSAN	Agriculture and Agro-Industry Department
OST	Office of Science and Technology
PBS	Program for Biosafety Systems
PCT	Patent Cooperation Treaty
PTM	potato tuber moth
PPP	public-private partnership; purchasing power parity
PUB	public understanding of biotechnology
PVY	potato virus Y
QUT	Queensland University of Technology
R&D	research and development
RABESA	Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa
RCC	regional consultative committee
REC	regional economic community
RECOAB	Réseau des Communicateurs ouest-Africains sur la Biotechnologie
RYMV	rice yellow mottle virus
SAATA	South African Agency of Science and Technology Advancement
SABIMA	Strengthening Capacity for Safe Biotechnology Management in Sub-Saharan Africa
SADC	Southern African Development Community
SANBio	Southern African Network for Biosciences
SARI	Savannah Agricultural Research Institute
SASRI	South African Sugarcane Research Institute
SCMV	sugar cane mosaic virus
SFSA	Syngenta Foundation for Sustainable Agriculture
SGRP	System-wide Genetic Resources Program
SEI	Stockholm Environment Institute
SIDA	Swedish International Development Cooperation Agency
SOCOMA	Société Cotonnière du Gourma
SOFITEX	Société Burkinabé des Fibres Textiles

SPEED	Statistics of Public Expenditure for Economic Development
SP-NK	Supplementary Protocol on Liability and Redress
SPS	sanitary and phytosanitary
SSA	Africa south of the Sahara
STI	science, technology, and innovation
STIP	segregation, traceability, and identity preservation
SUA	Sokoine University of Agriculture
TBT	technical barriers to trade
TIA	Technology Innovation Agency
TK	traditional knowledge
TRIPs	Trade-Related Intellectual Property Rights
TYLCV	tomato yellow leaf curl virus
UA	Unit of Account
UCB	University of California–Berkeley
UN	United Nations
UNCST	Uganda National Council for Science and Technology
UNEP-GEF	United Nations Environment Programme–Global Environment Facility
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNPCB	Union Nationale des Producteurs de Coton du Burkina
UPOV	International Union for the Protection of New Varieties
USAID	US Agency for International Development
USDA	US Department of Agriculture
USPTO	US Patent and Trademark Office
VR	virus-resistant; virus resistance
WABNet	West African Biosciences Network
WAEMU	West African Economic and Monetary Union
WAAPP	West Africa Agricultural Productivity Program
WASA	West African Seed Alliance
WECARD	West and Central African Council for Agricultural Research and Development
WEMA	Water Efficient Maize for Africa
WTO	World Trade Organization
ZPV	zucchini yellow mosaic virus

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DISCLAIMER

EXECUTIVE SUMMARY

The African Development Bank (AfDB), in commissioning this report to be prepared by the International Food Policy Research Institute (IFPRI), highlighted the need for a comprehensive, evidenced-based review of agricultural biotechnology in order to better understand its current status, issues, constraints, and opportunities for Africa. Agricultural biotechnology comprises several scientific techniques (genetic engineering, molecular marker–assisted breeding, the use of molecular diagnostics and vaccines, and tissue culture) that are used to improve plants, animals, and microorganisms. However, in preparing this desktop analysis, IFPRI has focused on genetic modification (GM) technologies in particular and on the agricultural context in which they are being applied, because GM technologies are at the center of the controversy about biotechnology's role in Africa. In addition, because we have attempted to focus our review on peer-reviewed evidence and documented examples, the preponderance of data presented in the report is focused on genetically modified (also abbreviated GM) crops in use and under development, although we recognize the potential of the technology for livestock, fisheries, and forestry. Our review includes the following:

1. an analysis of the development case—in context, based on current practice, and with an eye to future opportunities;
2. a review of key issues, both constraints and opportunities, related to capacity (in the broadest sense of the word), regulatory policy, intellectual property rights (IPR), trade, and natural resources; and
3. an overview of social policy, politics, and outreach.

Finally, we present a number of recommendations.

Common themes in all of the above are the absence of current and comprehensive data and the lack of centralized sources and complete databases from which to draw our conclusions. This was especially true of our analysis and discussion of Africa's capacity to use, absorb, create, and support agricultural biotechnology (agbiotech). As noted by Professor Gnissa Konate, minister of scientific research and innovation, Burkina Faso, "Data is critical as it will help answer important questions and assist in effectively moving biotechnology-related processes forward, especially in the area of regulation" (pers. comm., December 2011).

Obtaining better, Africa-specific data on biotechnology capacity and critical issues related to science, technology, and innovation to inform the debate is one of the primary recommendations of this study. In this regard, this report is a much-needed step in the right direction because it distills a number of the key points into one document while highlighting specific areas requiring further attention and resources.

A summary of our findings is presented by category below.

AGBIOTECH AND AFRICAN DEVELOPMENT

In the past few years, the global numbers of GM crops planted and rates of technology adoption have been steadily increasing, with the most impressive growth seen in developing countries among small-scale farmers. Nearly 15 years after the first commercial planting of a GM crop, the safety record of the technology suggests that the process of GM, per se, poses no significant risk to human health or the environment. Meanwhile, despite continued low agricultural productivity in most of the region and the high-stakes pressure to reverse a legacy of poor agriculture performance, Africa's approach to agbiotech has been cautious. Only four countries (Burkina Faso, Egypt, South Africa, and Sudan) have planted GM crops commercially, and only a few others (Ghana, Kenya, Malawi, Nigeria, Tanzania, Uganda, and Zimbabwe) have planted GM crops in confined field trials (CFTs).[1]

This study discusses the need to transform Africa's agriculture sector from one of historically low productivity to one that is a high-potential driver of economic development, drawing on technological and systemic improvements to foster intensification as opposed to extensification. The use of cutting-edge technology in agriculture is in line with global norms, represents a move toward rapid increases in yields and productivity, and is consistent with advanced development trends. The analyses conducted in this study support the need to use advanced technologies in order to reposition African agriculture as a competitive contributor in an evolving global bioeconomy. Faced with a variety of current pressures—population growth, poverty, food insecurity, climate change, and so on—most African countries, by adopting a status quo approach or by using outdated technology to drive the sector, will not be competitive in a global trade system that is increasingly using the tools of agbiotech to develop novel products. The transformation of Africa's agriculture system will require new approaches, new methodologies, new efficiencies, and the accompanying political focus needed to effect change.

Our review argues for a consideration of biotechnology in Africa from this context—one that has an expansive perspective that considers the short-term, albeit very important, requirements for food security and basic human development and also provides the basis for dynamic long-term growth and evolution that address future societal needs and opportunities in a holistic manner. Growth in intensive farming, fisheries, development of biofuels, sustainable forestry, and improved nutrition and health are all target areas that could benefit from an expanded and holistic vision. Biotechnology is one tool that can be used to achieve this reality, and it has been transforming agriculture elsewhere and in countries at various points on the development spectrum.

Nevertheless, the unique aspects of farming systems in Africa justify a more thorough examination of the technology and require a nuanced discussion. The small-scale and heterogeneous farming systems in Africa, especially compared to those of more advanced industrial agriculture systems, pose some issues with respect to the *stewardship, management,* and *ownership* of biotech crops—for example, impacts on natural resource management, approaches to insect resistance management, concerns about farmer-saved seed, applications in mixed cropping systems, relationships to inadequate seed systems, and impacts on women. The extent to which these issues have been thoroughly examined in an African context is debatable, even in those countries where GM crops have already been commercialized. Various concerns and factors could potentially be managed in ways that will allow technology optimization within socially and culturally acceptable parameters. However, this will require more thorough study and the development of various models and scenarios in order to better judge the technology in uniquely African situations.

In spite of the above, our review of the current literature and data supports the finding of overall positive impacts, even in Africa, on farmers who are using the technology. Savings in terms of increased gross margins, reduced pesticide costs, beneficial health and environmental effects, and improved yields over conventional crops in

1 In this report, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

the presence of pest pressure have been documented for small-scale farmers in Africa growing commercial GM crops. This is in line with findings in other emerging areas of the world.

Current data also support the contention that the accrued benefits are inversely proportional to the delivery time of the technology or its products to farmers. This specifically invokes the need to critically examine African seed distribution and delivery systems, as well as the complex system of laws and regulations that may facilitate or limit the technology's actual introduction. In short, regulatory and delivery factors are currently primary constraints to the timely accrual of benefits from the adoption of these crops.

Although the current data point to an average positive impact for GM crops, the data are nevertheless limited to only two of the four countries where the technology has been commercialized—Burkina Faso and South Africa—and to just two crops—maize and cotton. There are myriad products in the pipeline (bananas, cassava, cowpeas, and others) for eventual distribution to an expanded group of African countries: Ghana, Kenya, Malawi, Mozambique, Nigeria, Tanzania, and Uganda. A well-conducted ex ante socioeconomic impact analysis of the pipeline would be informative, would contribute to the current debate, and could be more relevant to a continentwide discussion of biotechnology.

KEY ISSUES

Capacity

The capacity of Africa to innovate, create, adapt, apply, and transform its agriculture sector using the new tools of biotechnology is, at this time, seriously deficient. For the purposes of this discussion we broadly define *capacity* to include human resources or technical capacity, infrastructure, financial resources, and the policy or legal climate. Our analysis was based on desktop surveys of existing sources and did not involve new data collection. For most African countries, data were nonexistent, incomplete, or old, thereby underscoring the need to support and update data collection methods and actions in order to obtain an accurate picture of the current situation and its resulting potential impacts for the future. Nonetheless, we performed a rapid comparative analysis based on a number of prospective indicators and performed a subjective ranking by country (see Table C.6).

According to our preliminary analysis, few countries possess the critical mass in agbiotech capacity that can be coupled to the supportive policies, structures, and political scenarios needed to actually use the technology. Although data are limited regarding the human and financial resources that countries in the region spend on biotechnology research and development (R&D), assessments have shown an erosion of agriculture spending in many countries. The observed spending increase in public agricultural R&D in Africa south of the Sahara (SSA) has been driven mainly by a few countries (Kenya, Nigeria, Tanzania, and Uganda), and the increase in the numbers of researchers has been coupled with a decrease in the share of PhD holders. These trends are inconsistent with the goal of a technologically adept and sophisticated agriculture sector.

Furthermore, the ongoing gender gap is pervasive and likely to affect Africa's ability to innovate and use biotechnology at all levels—from laboratory to farm to politics—unless specific interventions to broadly include the talents, creativity, and skills of women, currently an underutilized resource, are implemented. Information about impacts on women, gender-specific attitudes, and gender perspectives in biotechnology decisionmaking is largely nonexistent. The financial capacity to nurture and grow a biotechnology foundation for agriculture is also lacking; current policies (IPR, market, regulatory) are not conducive to investment and innovation; and the involvement of the local private sector, especially in the seed industry, is minimal. Despite a growing number of interesting public-private partnerships addressing Africa-specific constraints and developing some potentially interesting products, evidence appears to suggest that there is still limited capacity in Africa to determine what should be the future role of biotechnology on the continent. In the face of current trends, with a few exceptions, most countries are likely to depend on the involvement of specific private-sector interests or some combination of willing public-sector and international donors to actually develop products and applications for use by African farmers and consumers.

Regulatory Policy

The lack of regulatory policy governing GM products is one of the most detrimental factors affecting current biotechnology progress on the continent. There are a number of products that could provide immediate benefit to African farmers, but most farmers are unable to access these products due to poor regulatory decisionmaking capacity and indecisive political positions. The regulatory climate on the continent has been shaped primarily by discussions arising from the Cartagena Protocol on Biosafety under the Convention on Biological Diversity. The protocol's original scope was narrow, with a focus on identifying and mitigating any risks posed to biodiversity by genetically modified organisms (GMOs). In practice, it has become a de facto regulatory instrument for most of Africa; the strict, risk-oriented interpretations of the protocol (*the precautionary principle*) are the basis for the African Model Law on Safety in Biotechnology, which was initially developed by the Organization for African Unity and is now endorsed by the African Union (AU). The legacy has been that, as in many other developing economies, regulatory systems in African countries are largely driven by environment ministries despite the crosscutting nature of the technology.

To date, the regulatory capacity on the continent mirrors overall biotechnology capacity—it is fundamentally weak, with only a few countries in leadership positions. The technical command of issues by many regulators is limited, especially because few have practical experience with the technology. It is common for regulatory frameworks to present a conflicted approach that can be inconsistent with global norms (similar to those in evidence in Europe). A number of regulatory frameworks have strict liability provisions and unwieldy risk assessment requirements that are not commensurate with the risk currently posed by the technology. Most systems have not evolved from policy to practice. Finally, there is a distinct lack of harmony between biosafety laws and other legal frameworks, both nationally and regionally. Only one regional harmonization effort, undertaken by the Common Market for Eastern and Southern Africa (COMESA), has made sufficient progress toward becoming an operational reality with the 2013 approval of the Guidelines for Harmonization.

A few countries have taken bold steps toward the development of rational, balanced regulatory regimes: Ghana, Kenya, and Nigeria have passed national biosafety laws; Burkina Faso and South Africa have functional pathways for commercial product deployment in place; and Ghana, Malawi, and Uganda are implementing field trials to test a number of GM varieties. However, aside from these exceptions, most existing regulatory systems in Africa are inefficient and costly (unaffordable by local institutions), lack transparency, and are very risk averse. The degree of risk aversion embedded in these systems is not supported by an accumulating record of scientific evidence about the safety of the process and the products. Although a number of initiatives are under way to rectify the current regulatory paralysis, these are not always well coordinated or consistent in message or approach. Specific initiatives designed to eliminate confusion, coordinate disparate regulatory initiatives, build regional harmonization, and develop regulatory confidence at national levels could benefit local development and regional trade in GM products in those African countries positively inclined toward the technology.

Intellectual Property Rights (IPR)

The discussion of IPR has been highly charged in Africa; it relates only tangentially to biotechnology but affects innovation and scientific progress in general. The dialogue covers a tangled array of issues involving ethical concerns about the "patenting of life," concerns about monopolistic controls on food supplies, and the role of indigenous people as protectors of agricultural biodiversity. Although the focus has been on GM crops, the issues could apply to any number of agriculture innovations, including hybrid seed. Nevertheless, the debate has centered on agbiotech, further confounding the already murky landscape of this technology. Even though African countries have options (beyond patents) at their disposal to protect indigenous or external intellectual property assets, options that provide significant latitude for the respect of cultural norms while simultaneously protecting the "inventive" step, few have actually dissected the issues and made productive steps forward, despite various treaty obligations that require adherence to some form of IPR for plants and animals. The experience of many developed and developing countries points to the adoption of IPR systems as a means to drive national innovation—they are considered a significant element of a national competitiveness framework. Accordingly, training for a cadre of lawyers and technology transfer professionals in public-sector institutions is given priority as a means to implement national policy and drive or protect national innovation. Overall, there is a need for much education (training, workshops, conferences, and so on) on this topic at senior political levels, as well as at the level of practitioners.

Trade and Markets

The irregular adoption of GM products throughout the world and their limited acceptance in the EU, in particular, pose a number of trade-related issues for Africa. For the most part, GM products are traded internationally with minimal disruption. Trade in these products is governed by import-specific safety and marketing regulations, private standards, and consumer preferences. Research has shown that adoption of the current GM crops will be beneficial for African countries, despite perceived export risks, but that the regulations countries set will have an impact on their economic welfare. Research findings suggest that export risk to Europe and other countries should be assessed on a case-by-case basis to avoid excessive precautions as seen in the past in African countries. Import regulations for GM food should generally follow the Codex Alimentarius guidelines, as in other countries, but African countries may consider simplified procedures for GM products already in the market. Regional harmonization would facilitate trade while increasing the feasibility of functional import regulatory systems. The issue of the low-level presence (LLP) of unapproved GM products in the food supply chain will also need to be considered to avoid trade disruptions. Finally, marketing regulations, especially labeling policies, which are sought by many African countries, need to be seriously analyzed before introduction to avoid the creation of costly but unenforceable regulations that would confuse rather than inform unaware consumers. Similarly, documentation requirements that are being discussed in light of the Cartagena Protocol are expected to be costly and of limited use for regulators.

Natural Resource Management (NRM) and Biodiversity

Specific concerns related to the impacts of biotechnology on natural resources and biodiversity can be collectively grouped into three main areas: (1) effects on nontarget organisms; (2) gene flow, especially in centers of origin; and (3) risk management issues related to small-scale farmers and the informal nature of agriculture systems in Africa.

In general, the current body of evidence demonstrates that there are no negative environmental consequences that specifically result from growing GM crops. Much of the risk assessment data developed elsewhere is widely applicable to Africa. However, risks posed by the potential for gene flow or outcrossing must be considered on a case-by-case, trait-by-trait basis and should be evaluated in terms of basic evolutionary genetics, as is the case for any trait introduced into any plant by any means. For example, depending on the trait inserted, GM sorghum in Africa may require further scrutiny because the continent is a center of diversity in sorghum.

The situation is similar for effects on nontarget organisms. Such effects need to be evaluated on a case-by-case basis and in relation to other means of controlling pests or other risks that could be feasible or might alternatively be used in the specific setting. In many cases, because some GM crops are designed to be pest-specific and their introduction may result in the reduced use of chemical pesticides, the overall environmental impacts would be neutral or even positive. Issues related to loss of biodiversity due to changes in farming practices (monoculture versus polyculture cropping systems) also need further contextual analysis; potential outcomes must be weighed against the status quo or alternative farming systems, some of which represent significant current threats to biodiversity due to NRM pressures resulting from extensification, deforestation, and desertification.

One area that will require further discussion and analysis relates to *on-farm management of GM crops* by small-scale farmers, especially with regard to crops that are developed and released by the public sector and thus may not have the same level of scrutiny and consistent support as commercial products. This is especially true in Africa, where most government extension services are weak and underfunded. As in the case of all agriculture technologies, GM technologies may require some specific management methods to protect the viability of inserted traits, especially for single-trait or single-mode-of-action gene insertions. Insect resistance management is a recognized area of concern for all farmers but poses a particular concern for small-scale farmers, who may lack training and may not adopt the recommended practices to control insects. For commercial products, various technical approaches are in use, including the insertion of multiple genes with various modes of action to deliver the desired effect. This may not always be feasible for public-sector crops. Various models, whether technical or policy oriented, will need to be developed to ensure that appropriate stewardship strategies are followed by small-scale farmers to protect the efficacy of GM products.

POLITICS, POLICY, ANTD OUTREACH

Biotechnology, including genetically modified crops, can contribute to the goals set by African countries in their development plans. GM and other biotechnologies can help address low productivity and profitability issues, as well as food security issues that have proven to be intractable by other means. Technologies such as those to increase drought and salt tolerance and to enhance nutrient use and nutritional composition can help improve the livelihoods of smallholder farmers. Accessing biotechnologies, GM in particular, will be dependent on the environment in which the technologies will be deployed. Like regulatory policy, this is also a critical area for attention because the level of misinformation about biotechnology in African countries is extraordinarily high, even when compared, anecdotally, to that in other developing areas. Again, as is the case of other topics in this report, a comprehensive survey about attitudes across the continent does not exist. Current national baseline surveys are also limited, leading to a situational analysis based mostly on conjecture.

A number of communication and outreach initiatives have been mandated, such as that of the AU, or have been pursued by various bilateral donors and multilateral funding agencies. These have not been sustained over time, nor have they been approached strategically; identification of the information needed, for whom, and by what means it is to be collected has not been systematically evaluated and addressed. In Africa, a communications approach based on an arbitrary division between consumers and farmers is not useful because the percentage of the population engaged in farming far exceeds that of more advanced countries. Clearly, outreach and communication strategies must be tailored to meet the particular needs of Africa in this regard. In addition, the current strategies for delivering information will require a comprehensive review because the level of disagreement and misinformation about biotechnology in Africa is substantial. Stratified baseline data on perceptions and the value of various communications methods do not exist and are needed for an informed outreach approach. Methodologies such as IFPRI's net mapping tool can be highly effective in delineating influential networks and defining points of intervention for message development and information delivery. These would include defining an approach to consistently inform high-level political influencers, either individually or collectively, through formal structures such as the AU or regional economic communities (RECs). In addition, outreach to media, civil society, religious organizations, and scientific communities will require a similar systematic analysis of concerns, messages, delivery mechanisms, and levels of societal influence. Initiatives currently under way have been more or less ad hoc and have not attained the level of detail and rigor needed to thoroughly address the lack of clarity and miscommunication that exists. However, there is generally a consensus in Africa that a concerted outreach effort is needed to move the continent forward from its current bifurcated position.

RECOMMENDATIONS

The analysis in this report demonstrates underinvestment, weak capacity, and weak regulatory structures for biotechnology. Therefore, efforts to increase public investment in biotechnology and to upgrade and strengthen science-based, cost-effective regulatory systems should be seen as the highest priority. Below is a series of recommendations that can provide a strong supportive foundation for biotechnology development, if implemented.

- Provide increased financial support for investment in public agricultural R&D related to biotechnology and GM technology.
- Provide support for regulatory capacity building, including the harmonization of efforts and facilitation of better coordination based on an impact assessment of current approaches and activities.
- Develop an ex ante socioeconomic impact analysis of an expanded group of key products under development in order to engage especially those African countries that currently have limited experience with the technology. This will be useful to more broadly inform the political and policy dialogue.
- Collect better data with respect to a range of issues related to biotechnology in Africa—technical capacity, infrastructure, policy capacity, regulatory capacity, IPR

policies, financial resources, project impacts, gender impacts, and product pipeline data, among others.

- Update the current database of public-sector projects, and identify the lessons learned for product development.
- Undertake a gender analysis that examines the differentiated impacts of GM technologies on women and men, and develop and implement an initiative to engage and raise awareness among women at all levels of society in the ongoing debate about biotechnology for Africa.
- Pursue an expanded dialogue or initiative with new African trade partners (emerging countries such as Brazil, China, and India) about biotechnology, and foster public- and private-sector research activities.
- Explore a number of discrete actions (workshops, training, capacity-building initiatives, and so on) to encourage a nuanced and informed dialogue about intellectual property and biotechnology, and develop capacity to negotiate intellectual property and licensing agreements, especially at the institutional level.
- Using innovative tools and methods for social network analysis, devise and implement a comprehensive strategy for outreach and communication, and initiate a baseline assessment of current attitudes and perceptions about biotechnology in Africa.

Introduction and Purpose of the Report

It has been 60 years since the discovery of the double helix by James Watson and Francis Crick—a milestone in scientific history that has been credited with launching the "genetic revolution" and a global, multibillion-dollar biotechnology industry. In the face of an unprecedented cultural war about science, largely initiated and perpetuated by US-European disagreements about the applications of this technology to agriculture, emerging economies in the developing world have been adopting a range of first-generation products (largely in the form of new plant varieties) at rates surpassing those of their more economically developed counterparts. Sitting largely on the sidelines of this debate and in the adoption of this technology is the continent of Africa. And, once again, the déjà vu comparisons to the Green Revolution and the possibility that another scientific revolution will pass the continent by have become unmistakably familiar.

Agriculture contributes about 35 percent to the continent's gross domestic product (GDP), accounts for 70 percent of the labor force, and is considered a key catalyst in the overall economic development of African economies (Juma 2011). And yet sector statistics continue to disappoint. Nearly one-third of African countries face chronic malnutrition. Africa continues to import 25 percent of its food despite the fact that 70 percent of its population is engaged in agriculture (Paarlberg 2008). Farm production continues to decline (the levels in 2005 were 20 percent lower than in 1970), yet fewer than 30 percent of African farmers have access to or use improved seeds (Paarlberg 2008).

In the context of these discouraging statistics, Africa's hesitancy to join the "gene revolution" (while somewhat understandable due to myriad issues that will be discussed in this report) seems incongruous when juxtaposed against the obvious need to transform the agriculture sector from its business-as-usual approach. Although many of the newly emergent economies (Argentina, Brazil, China, and India) are embracing the tools of biotechnology to improve their agricultural economies, with the exception of South Africa, uptake across the African continent has been largely anemic. Subsequent declarations at Maputo in 2003 and at the African Union (AU) Summit of 2009 of the need to rapidly raise the productivity of the agriculture sector have done little to affect the stalemate in the biotechnology debate. A high-level African panel on biotechnology established under Africa's Science and Technology Consolidated Plan of Action (CPA) called on the AU to "facilitate open and informed regional multi-stakeholder dialogue on, inter alia, scientific, technical, economic, health, social, ethical, environmental, trade and intellectual property protection issues associated with or raised by rapid developments in modern biotechnology" (Mugabe 2003, 2). Seven years later, this recommendation has not been implemented in a systematic, sustained, and coordinated fashion. As a result, there has been limited progress toward the resolution of the tensions surrounding this technology.

In light of the potential of biotechnology to contribute to growth, development, and poverty reduction in Africa, given the 17-year history of use of the technology, the African Development Bank (AfDB) has engaged the International Food Policy Research Institute (IFPRI) to develop an up-to-date study on the current situation of agricultural biotechnology in Africa. The purpose of the study is to inform the AfDB with respect to Africa's opportunities, capacity, policies, constraints, and concerns regarding the uses of agricultural biotechnology (agbiotech) on the continent. AfDB does not currently have a policy or strategy on biotechnology.

For the purposes of this report, we are limiting our discussion to those sets of technologies commonly referred to as genetic modification (GM) technologies (involving the use of recombinant deoxyribonucleic acid [DNA] techniques to move genes within or between species), because these have proved to be the most controversial. In addition, because we have attempted to focus our study on peer-reviewed evidence and documented examples, the preponderance of data presented in the report is focused on GM crops in use or under development, although we recognize the potential of the technology for livestock, fisheries, and forestry, which are discussed in brief. IFPRI is well placed to generate such a report. The Institute is a world leader in agriculture policy research and is specifically recognized as an independent and credible source of information on this topic. IFPRI brings to this task an extensive record of research focused on the issues and impacts of biotechnology on developing world agriculture, especially in the areas of trade, biosafety, socioeconomics, and issue analysis in relation to the Cartagena Protocol. These are areas that, among others, have greatly influenced the current state of affairs in Africa. In some instances we have also drawn on a variety of reports and documents from recognized and knowledgeable sources and have relied on an extensive database of African practitioners (both policy and technical) for supplementary information and personal knowledge. Our intention is to present a reasoned, objective overview of the situation backed, where possible, by available evidence, while maintaining distance from the hyperbolic rhetoric frequently seen on both sides of this debate.

We present this information with one major point of caution: *comprehensive data with respect to Africa and agbiotech are often outdated, incomplete, or in many cases nonexistent, decentralized, or disaggregated.* These include data on technical and human capacity, infrastructure, projects, policies, investments, private-sector activity, political positions, and outreach initiatives. Databases, such as the Food and Agriculture Organization (FAO) database, do not fully capture a comprehensive picture, and data collection initiatives focused on evaluating research and development (R&D) capacity, including IFPRI's Agriculture Science and Technology Indicators (ASTI) initiative, do not segregate information in specific technology categories (such as biotechnology). Nor do they typically capture information with respect to capital infrastructure (that is, laboratory facilities, equipment, country investments). In light of this data gap, one key recommendation from our findings will be to initiate comprehensive data collection activity that uses detailed surveys and modern data collection methodologies and that could provide data that form the basis of a biotechnology-focused database that could be continuously updated. Such a database would have immense utility to inform key investors, policymakers, and political bodies about the actual state of affairs with respect to this technology in Africa.

The following report is organized into four sections that cover these topics: the status of and perspectives on agricultural biotechnology, as well as an overall view of the agriculture sector in Africa; key biotechnology issues, including capacity, regulatory policy, trade and markets, and natural resource management (NRM); the roles of biotechnology donors and communications and outreach; and finally specific recommendations for moving forward. The report also has three appendixes: the first includes summaries of the state of crop biotechnology for selected countries; the second provides a rapid assessment of the national biotech innovative capacity in Africa; and the third contains some of the longer tables that are referred to in the text of the report.

Agricultural Biotechnology (Agbiotech) and African Development

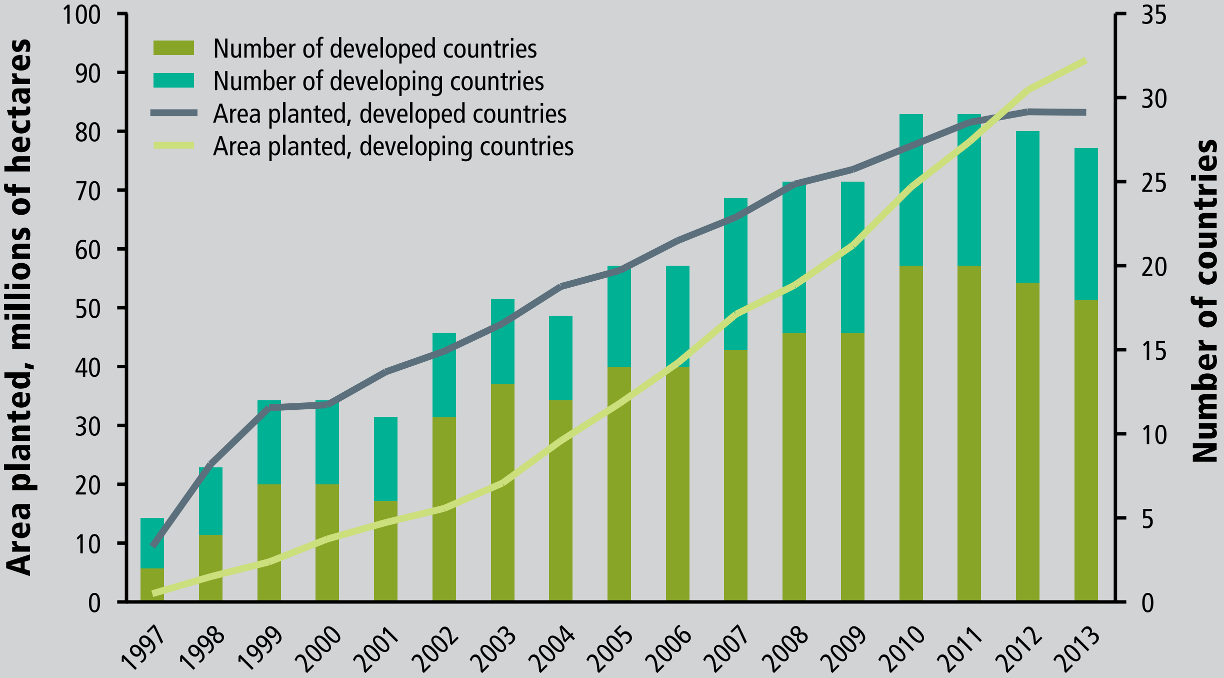
THE GLOBAL SITUATION

At the pivotal Agenda 21, the United Nations Conference on Environment and Development, held in 1992, four years before the release of the first commercially available genetically modified (GM) plant varieties, biotechnology was identified as a potential contributor to the achievement of global sustainable development goals. More recently, the Bio-resources Innovations Network for Eastern Africa Development (Bio-Innovate) program has recognized the tools of modern biotechnology as necessary components for the development of a knowledge-based global bioeconomy (Bio-Innovate 2010). Bio-Innovate's founders contend that a dynamic, knowledge-based agriculture sector will be important to (1) develop resource-efficient and productive agriculture systems for climate change adaptation; (2) decrease dependency on fossil fuels for energy, leading to fewer greenhouse gas emissions; (3) revitalize rural economies by increasing the production base for value-added products; and (4) recycle energy and material flows for the mitigation of environmental degradation. Biotechnology is considered a critical means to achieve these goals.

Despite this history and acclaim, both past and present, in about 17 years since the first commercialized crop release and after the planting of more than 1 billion hectares of GM varieties by more than 15.4 billion farmers, controversy regarding the role and relevance of this technology to safely and positively affect the poorest countries of the world persists (James 2010). The 87-fold increase in hectares planted with GM crops from 1996 to 2012 is an unprecedented accomplishment in the history of modern agriculture (James 2012). Although farmers in the developed world were at the forefront of the early adopters, between 1997 and 2013 the highest annual growth rates of areas planted with GM crops were achieved by developing countries; 22 percent was the average annual growth rate in those countries versus 10 percent in developed countries (Figure 1).

As previously stated, most agree that the nexus of this debate has its origins in a sociopolitical disagreement between the United States and the EU. Elements and underpinning circumstances of this dispute will surface elsewhere in this report. Not surprisingly, Europe continues to lag behind the global norm of industrialized

FIGURE 1 Numbers and global area of countries with biotech crops, 1997–2013



Source: Authors' elaboration of data from James (1998, 2000, 2002, 2004, 2006–2010, 2012–2013).

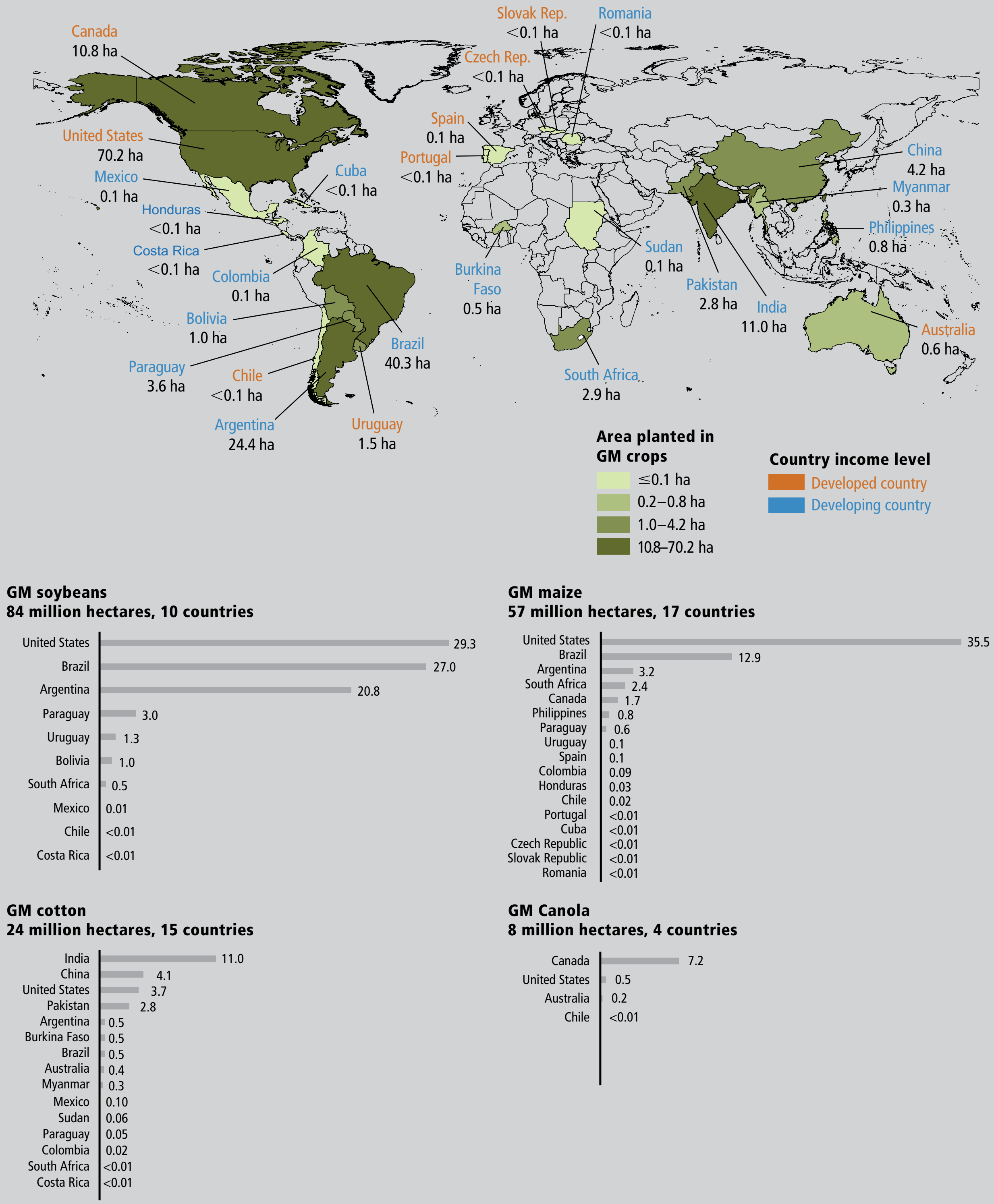
Note: Classification of countries as "developed" and "developing" is based on the World Bank (2014) classification of countries by income. All countries that in 2012 had a gross national income (GNI) per capita of US$12,616 or more are classified as high income and in this figure as developed. All other countries, with less than US$12,616 GNI per capita, are classified as developing.

countries with respect to adoption rates. But despite continued resistance by EU consumers and a growing preference for organic production methodologies in Europe compared to other areas of the world, plantings of GM crops even in some European countries are slowly increasing (James 2013). According to research by the Brussels attaché of the US Department of Agriculture (USDA), Portugal's sowings of Monsanto Company's GM variety MON 810 (engineered to protect maize against insect pests) increased by 50 percent, to 7,300 hectares, in 2011 and was 8,000 hectares in 2013 (James 2013). In Spain, cultivation figures for the same variety rose by 4.7 percent, to 80,200 hectares, in 2011 and by 2013 reached 136,000 hectares (James 2013), representing about one-third of the 471,464 hectares planted in Spain (MAGRAMA 2014). As depicted in Figure 2, in 2012 GM crops were grown in 5 European countries, which included 3 that grew the *Amflora* potato variety, the first GM crop approved for planting in the EU in 13 years. These figures and data contradict the conventional wisdom held by many, especially those in Africa, that GM crops are not planted in Europe.

In 2014, among the developing world economies, Brazil, Argentina, India, and China are leading the way, with 40.3, 24.4, 11.0, and 4.2 million hectares of GM crops in cultivation, respectively (see Figure 2). This compares to a US figure of 70.2 million hectares. In 2013, and for the third year in a row, Brazil led the way among all countries in increased plantings of GM crops (up by more than 10 million hectares from 2011). And despite an otherwise contrary picture for Africa, Burkina Faso had the second-largest annual proportional increase, 126 percent, devoted to GM cotton, and Sudan is now the fourth African country to have commercialized GM crops (James 2013).

To date, GM varieties of maize, soybeans, and cotton, mostly engineered for pest and herbicide resistance, make up the majority of the crops accounting for these figures (see Figure 2). However, many additional crops are in the pipeline, some of which will have more specific relevance to many of the emerging world economies: cassava, cowpeas, potatoes, rice, sorghum, and other tropical crops. As discussed later in this section of the report, many of these GM varieties in the pipeline may have direct relevance for Africa.

FIGURE 2 GM crops: 175.3 million hectares planted in 27 countries, 2013



Source: Authors' elaboration of data from James (2013); USDA (2013).

Notes: ha = hectares. All other GM crops—apart from GM soybeans, maize, cotton, and canola—account for around 1 million hectares in 5 countries. Classification of countries as "developed" and "developing" is based on the World Bank (2014) classification of countries by income level. All countries that in 2012 had a gross national income (GNI) per capita of US$12,616 or more, which are classified by the World Bank as high-income countries, are classified in this figure as developed. All other countries, with less than US$12,616 GNI per capita, are classified as developing. This map depicts the former Sudan, which is now two independent nations, Sudan and South Sudan.

The global picture with respect to agbiotech is trending toward one of adoption rather than rejection of the technology. Africa, which faces the most serious food security challenges of all world areas, lags far behind and, to date, continues to exhibit a cautious rhetoric that follows that of its major historical trade partner, the EU. Developing trade and investment opportunities with major new adopters (such as Brazil, China, and India) as well as the potential for inter-African trade in GM food and feed crops may affect this dynamic in the future and may catalyze much-needed regulatory harmonization, but, for the moment, attitudes in the EU appear to be the prevailing influence.

In Africa, only Burkina Faso, Egypt (at least until 2012), South Africa, and Sudan (since 2012) have commercially grown biotech crops. Kenya, Nigeria, and Uganda (and more recently Ghana, Malawi, and Mozambique) are field testing a variety of other crops (cassava, cowpeas, bananas, cotton, maize, rice, and sweet potatoes) that have been developed via public-private partnership (PPP) arrangements with donated technologies. These are in the minority. Most of the continent lacks biotechnology research and development (R&D) activity in either the volume or the intensity of effort and resources needed to address current agriculture productivity constraints in a meaningful way. Lack of technical capacity and political will, contradictory attitudes of regulatory bodies, weak and inefficient regulatory frameworks, trade concerns, and public misinformation or misperception are presenting a number of challenges that African countries have not been able to overcome. For many, these are real concerns; and although a number of these constraints tend to be relevant to agriculture innovation, in general, the prevailing attitude of controversy with respect to agricultural biotechnology further elevates the acceptance and adoption hurdles that must be overcome.

OVERVIEW OF THE AGRICULTURE SECTOR IN AFRICA: SETTING THE CONTEXT

The state of African agriculture has been described and debated perhaps more than any other development issue over the past half century. In this section we provide a brief contemporary overview of the key conditions and trends shaping agriculture and food security in Africa. The focus is on illuminating challenges that will, in subsequent sections, be diagnosed from the perspective of scoping innovation needs. We pay particular attention to avoiding pitfalls that have undermined past efforts at promoting "solutions" to Africa's mostly disappointing agricultural performance (although the situation is more encouraging in a few countries, such as Ghana and Malawi). We have learned about the following:

1. the need to recognize and account for the strong heterogeneity in agroecological, economic, and cultural conditions under which farming is practiced across the continent;
2. the weakness of institutions mandated to nurture, transform, and regulate agriculture and related sectors, including agricultural research and extension service providers;
3. the high exposure to risk (and hence the strong risk aversion) of poor farming households, partly arising from these environmental and governance factors but compounded by the debilitating threats of disease (human, crop, and animal) and conflict and the lack of functioning social safety nets; and
4. finally, the fundamental disconnect between the predominant role of women and children in the conduct of African agriculture and conventional approaches to the design and targeting of agricultural innovations.

We do not offer a discussion of biotechnology and its relevance to Africa, per se; but we do define the parameters around which any discussion of biotechnology should take place.

The case for science, technology, and innovation as key drivers for agriculture productivity and economic development has been well established via a preponderance of evidence and well-analyzed case studies. Juma (2011) invokes a paradigm shift about the role of agriculture in development. That invocation abandons a more traditionally held view of agriculture as a transient contributor in the continuum of agrarian to industrial development and recognizes its more holistic and increasingly crosscutting impacts on "income growth, poverty alleviation, food security, gender empowerment, and the supply of environmental services" (Juma 2011, 5, quoting Pingali 2010). This presumption accords an even more critical and prioritized role to agricultural development and paves the way for a scenario of major opportunities for those newly emerging economies that embrace agricultural innovation. One could argue that "new" agriculture sciences might be the catalytic drivers of the rejuvenated approach that is needed to address the rapidly evolving global bioeconomy. It is within this context that one must consider the current situation facing Africa's agriculture sector, a sector that is far from this dynamic picture of "farming for the future" but that, nonetheless, has enormous transformative potential. Discussions about the rightful place and role of biotechnology should be considered against this backdrop of current reality and future potential.

The Unprecedented Food Challenge

Between 1980 and 2003, population growth in Africa outstripped that of any other region of the world, increasing by more than 50 percent, and that trend is set to continue until midcentury, albeit at a slower rate than the current 2.3 percent per year (UN 2009). As a consequence, Africa's population will grow from around 1.1. billion in 2013 to 2.4 billion in 2050 (FAO 2014b). That unprecedented population growth—which will more than double the current total population of Africa—will be accompanied by major structural shifts that will see Africa transform into a predominantly urban region.[2] Also expected are low but rising incomes (projected growth rates in per capita gross domestic product [GDP] of around 3.5 percent per year) and changes in urban lifestyle (Nelson et al. 2010), which will bring about major shifts in consumption, such as an increased demand for meat and fish, and hence for animal feed; for wheat and rice, oil and sugar crops; and for higher-value fruits and vegetables (FAO 2011b, 2012). In all, Africa will essentially need to *triple its food availability* between 2000 and 2050, and will have to aim even higher if the quantity and quality of food it produces are to increase nutrition levels on a continent where almost 30 percent of the population is undernourished (FAO, WFP, and IFAD 2012). Such considerable growth in food demand—coupled with expectations about Africa's ability to increase output, the impacts of climate change, and the potential competition for land planted with energy crops—is projected to reverse the downward trend in real food prices of the past half century and herald a new era of food price increases (Nelson et al. 2010; Msangi and Rosegrant 2011).

The farmers of Africa and those that support them—governments, public- and private-sector research and development institutions, nongovernmental organizations (NGOs), and others—will need to intensify production at a pace and with a level of resource use efficiency that is unparalleled in human history. Many of these challenges have proved to be intractable by existing approaches such as conventional plant breeding and agronomic practices. Biotic and abiotic stresses, the lack of nutrient and water availability, and poor nutritional composition—in many cases made worse by the new challenges of climate change risk—have constrained productivity in the past. Biotechnology, and GM biotechnologies in particular, have opened the possibility of addressing binding abiotic and biotic constraints in Africa. The broad spectrum of opportunities opened by biotechnology, including GM biotechnologies, can lead to an improvement in farmers' livelihoods in the region. These opportunities can also benefit consumers in urban and rural areas while making it possible to enhance the rural farm and nonfarm sectors of the economy.

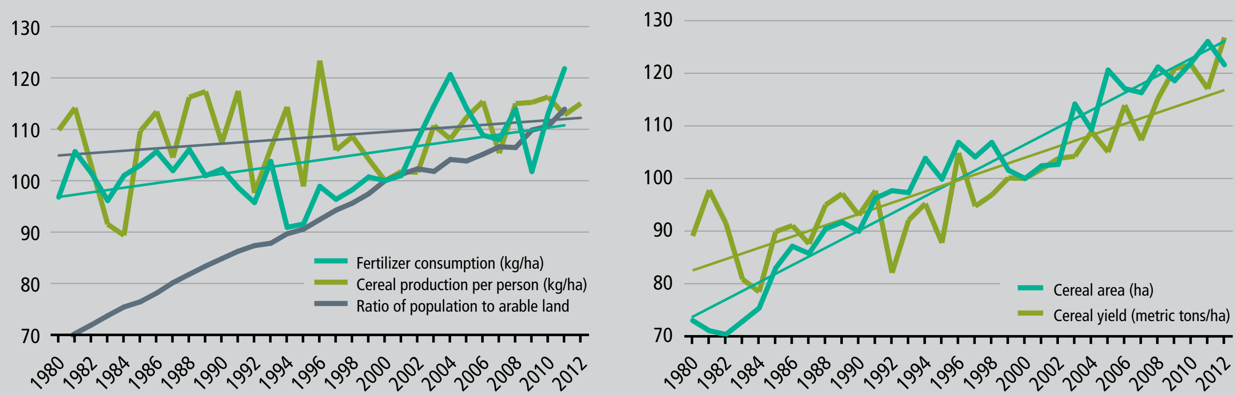
Business as Usual: Not an Option

Some stark clues to the severe challenges faced are revealed by an overview of key trends in the region. Aggregate trends mask the great variability across and within countries, but they also reflect the major patterns of development. Without urgent and sustained actions to reverse the trends revealed by these indicators, the persistent food security crises will only be exacerbated. Although the share of the population in Africa that is undernourished has fallen over the years (from 27.3 percent in 1990–1992 to 22.9 percent in 2010–2012), the number of those who experience chronic hunger has risen from 175 million to 239 million over the same period (FAO, WFP, and IFAD 2012).

Food availability has grown at rates similar to that of the population. Taking cereal production as a general measure of food availability, although cereal output has kept pace with contemporary population growth and the availability per capita has slowly risen, the pressure on land resources to sustain continued growth has risen much faster (Figure 3). The underlying data (FAO 2014b) used to calculate the indexes pictured in Figure 3 show that in 1980, 10 hectares of African cropland was needed to sustain about 28 people. By 2012, that number had risen to 48 people. One way to sustain crop productivity is through the increased use of fertilizer, but average fertilizer consumption has remained essentially static over the past 30 years. As a consequence, the primary means of meeting increased demand and compensating for the loss of land with depleted nutrients has been to open up new land and expand the agricultural frontier. Between 1980 and 2011 (FAO 2014b), the total cereal area in Africa grew by

2 The urban population of Africa is expected to surpass the rural population around 2030, when urban and rural populations will both be over 915 million. Although the rural population is expected to increase by around 160 percent between 2000 and 2050, the urban population will see a staggering increase of 342 percent (FAO 2014b).

FIGURE 3 Trends in selected food production indicators for Africa, 1980–2012 (2000 = 100)



Source: Compiled by authors from FAO (2014b).

Note: ha = hectare; kg = kilogram.

67 percent, from 64 million to 106 million hectares, while the average cereal yields grew by only 42 percent, from 1.1 to 1.6 metric tons per hectare. This is an inverse of trends in all other regions of the world, where intensification of production (increase in yield) has been the primary driver of output growth (FAO 2014b). Continued conversion of land to agriculture is not a sustainable option as the competition for land increases and the amount of suitable agricultural land as yet unexploited continues to diminish (Godfray et al. 2010).

A further insight into the enormous challenge of transforming African agriculture not only to meet its future food needs but to do so in ways that allow for sustainable production by limiting the degradation of land, water, and biodiversity resources is provided in Figure 4. Here the distribution and severity of some key biophysical constraints to agricultural productivity are illustrated. Drought, pests, and diseases are represented by the potential prevalence of just one pest, the maize stem borer, and soil fertility constraints are represented by the distribution of high levels of phosphorus fixation in the soil (phosphorus deficiency is a major soil nutrient constraint on the continent).

In addition to these ongoing challenges and perspectives in Africa, climate change will have even further impacts on agricultural production and food security. Variability in temperature and rainfall patterns has added uncertainty and vulnerability to the production process. Under these circumstances, the modern tools of biotechnology and genetic engineering could play an important role because they can mitigate climate change through the production of crops that are amenable to low-till agriculture systems, resulting in enhanced carbon sequestration in the soil. In addition, because the use of GM technology has the potential to greatly reduce the generation times for new varieties and can draw on beneficial traits resident in other species that are not easily introduced via conventional breeding, the technology offers a selective advantage for the creation of "tailored" varieties to meet evolving agroecological conditions.

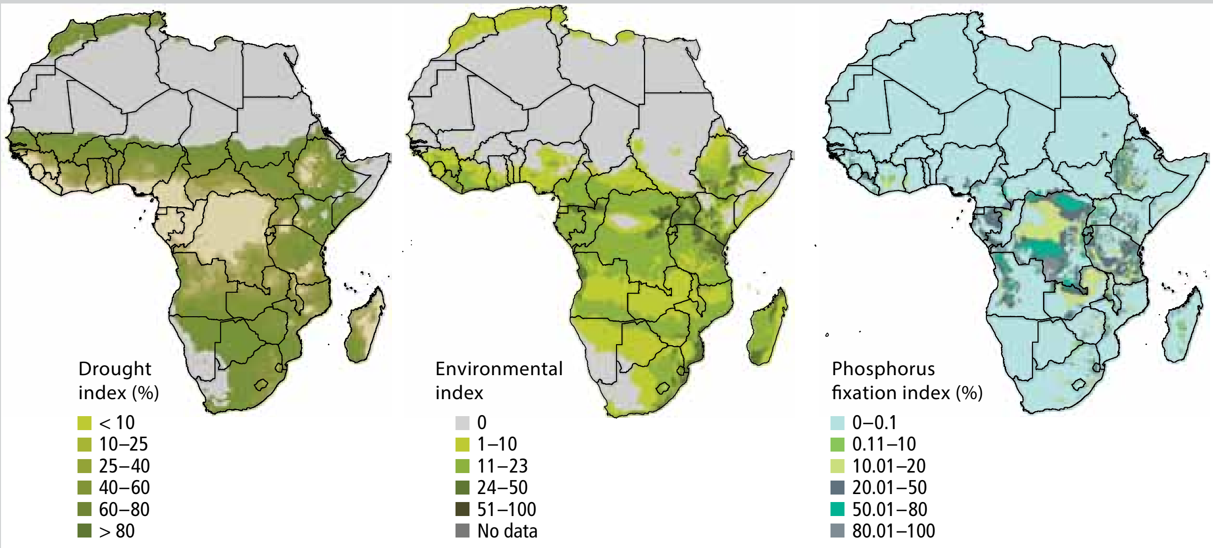
An obvious example is the development of drought-tolerant crops (already under way) or crops that can use nitrogen more efficiently or are able to grow in high-salt soil environments. These multitrait characteristics needed to address abiotic stresses are very difficult to achieve, if not impossible in some cases, through conventional breeding. The advancements in genetic engineering and the reduction in the cost of gene sequencing have opened up new ways to develop crops that can specifically target these challenging, and increasingly climate-induced, constraints (Godfray et al. 2010; Rosegrant et al. 2014). These developments, along with conventional approaches, will contribute positively to the enhancement of the conditions for smallholder farmers and poor rural and urban consumers by improving farm-level profitability while helping to enhance food security and access by reducing production costs and increasing efficiency.

BIOTECHNOLOGY AND AFRICAN SEED SYSTEMS

As we consider the context for GM crop technology in Africa, it is important to reflect on the current situation of African seed systems—how seed is produced, accessed,

FIGURE 4 Spatial distribution and intensity of selected biophysical crop production constraints in Africa, 2010

A **Drought:** Years with a failed growing season B **Pest prevalence:** Potential prevalence of spotted stem borer C **Soil fertility constraints:** High levels of phosphorus fixation in the soil



Sources: Drought—Map elaborated by HarvestChoice using aridity index data available from Zomer et al. (2007, 2008). Pest prevalence—Hutchison et al. (2008). Soil fertility constraints—HarvestChoice (2011).

Notes: Panel A—Drought index = percentage of years with a failed growing season. Panel B—Environmental index = measure of likely pest prevalence on a scale of 0 (pest damage is very unlikely) to 100 (environmental conditions are very favorable to pest damage). Panel C—Phosphorus fixation index = percentage of area with a high level of phosphorus fixation. Panel B depicts the former Sudan, which is now two independent nations, Sudan and South Sudan.

distributed, and used. Getting this context right will be critically important if the full benefits of improved GM seeds are to be realized in Africa.[3]

Informal seed systems dominate the seed sector in most of Africa and have served an important role in securing seed provisions, distributing seeds, and saving seeds by small farmers, as well as providing the required seeds in times of stress and crisis (Sperling 2010). Farmers' demand for quality seed is universal, and yield stability is a desirable trait for all farmers. To be able to provide such traits, a well-developed formal system needs to be in place. In many African countries, quality seed (regardless of the process by which it is produced—via traditional breeding or biotechnology) is inaccessible to most farmers because of historically weak linkages between farmers, extension systems, research institutions, and the commercial seed industry. Langyintuo et al. (2008) have identified many of the bottlenecks in the development of a formal seed sector in African countries, including delays in variety registration and release, overregulated seed policies, poor infrastructure, and the lack of financing.

The dominance of seed systems by the public sector and farmer-to-farmer transactions, small and disaggregated seed producers with limited capacity, and weak distribution systems are contributing factors in the current poor performance of African seed systems and are limiting the adoption of GM seeds. The situation is further compounded by weak or nonexistent seed quality control systems that have led to the counterfeiting of seeds, a rampant phenomenon in countries such as Ghana, Kenya, Nigeria, Tanzania, and Uganda (Van Mele, Bently, and Guei 2011). This poses a problem, particularly for the marketing of GM seeds, given that expectations of high performance are a key component of private-sector marketing campaigns. Few African countries have comprehensive and modern seed legislation. Even in countries where new national seed laws have been passed, implementation has been impeded by inadequate enforcement mechanisms and the lack of logistical, financial, and human resources. As documented by Van Mele, Bently, and Guei (2011), there are, nevertheless, interesting success stories for some seed companies

3 Perspective for this section is contributed by the African Seed Trade Association.

in Cameroon, Gambia, Guinea, Kenya, Mali, Morocco, Nigeria, and Uganda from which we can draw important lessons for the future development of a sustainable seed sector in Africa.

Improved farmer access to quality seed will be fundamental to the success and adoption of biotechnology in Africa. Formal cross-border movements of seed are likely to be severely hampered by the lack of harmonized phytosanitary regulations, seed certification standards, and variety release protocols. When this situation is juxtaposed against new biotechnology regulatory protocols, the lack of synchrony could lead to additional delay and inefficiencies for new GM variety approvals nationally and regionally. This would eliminate the technical advantage of breeding in terms of the time savings, costs, and efficiencies that would be expected from using genetic engineering to generate new varieties. Furthermore, informal movement of GM seed between countries with varying regulatory capacities and structures could give rise to further public debate and safety concerns about uncontrolled "genetic pollution." Recognition of the need to address these constraints is becoming more apparent. Regional economic communities (RECs) such as the Common Market for Eastern and Southern Africa (COMESA), the Southern African Development Community (SADC), and the Economic Community of West African States (ECOWAS) have recently launched initiatives to harmonize seed policies, trade-related regulations, and, to a lesser extent, biosafety systems within their jurisdictions. At the national level, some efforts are under way to reconcile existing seed and phytosanitary laws with newly developed biosafety regulations.

One initiative worth mentioning is the project Strengthening Capacity for Safe Biotechnology Management in Sub-Saharan Africa (SABIMA) of the Forum for Agricultural Research in Africa (FARA), funded by the Syngenta Foundation for Sustainable Agriculture (SFSA). This project has an important training component on stewardship in biotechnology. SABIMA has taken a "life cycle" approach to stewardship management and seed quality issues governing handling and good practices from research to the field—seed producer and grain producer—to variety discontinuation.

The lack of adequate participation by the private sector (such as local seed suppliers) in seed trade and distribution, as well as the lack of organization in the seed market and economically viable seed markets, are impediments to seed-sector development in Africa in and of themselves and could severely affect the uptake of new biotech varieties if not addressed. A flexible, revitalized, and modern seed system and an informed seed supply system are crucial to effectively respond to the challenges identified. Seed suppliers, in particular, can be an effective interface between seed companies and farmers and provide a conduit for information about GM crops. Given the current status of seed production systems in most African countries, support to build the capacity of small seed companies will be required if they are to play effective roles in the deployment of biotech seeds to farmers.

The African Seed Trade Association (AFSTA), in collaboration with the RECs, is leading a major capacity-building effort to build the commercial seed platform in Africa. For example, the Alliance for the Seed Industry in Eastern and Southern Africa (ASIESA) is a PPP whose goal is to create a reliable source of improved seed for eastern and southern Africa by holistically addressing the challenges and constraints facing the supply of commercial certified and high-quality seed to farmers. ASIESA was started by AFSTA and COMESA in 2010. The West African Seed Alliance (WASA), another PPP, has a goal of establishing a viable commercial seed industry in West Africa. It was initiated in 2007 in collaboration with the US Agency for International Development (USAID), ECOWAS, the Alliance for a Green Revolution in Africa (AGRA), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), among other stakeholders. The two alliances are multidonor initiatives whose success will depend on strong support by various donors and governments.

In a bid to expand the seed market, AFSTA is working closely with RECs such as COMESA, ECOWAS, and SADC on the seed policy harmonization initiatives referenced above. The success of these initiatives will help ensure that biotech crops will find a more facilitative seed system and trade environment on the continent. However, in most of the agreements, GM crops are not considered until the countries develop national or regional policies governing the release of these varieties. The harmonized rules are expected to facilitate cross-border seed consignments to alleviate periodic seed shortages in some countries, thereby encouraging further investments. Even so, most countries in Africa still need to pass biosafety laws to facilitate biotech research, development, and deployment. Passage of laws providing for functional biosafety systems has contributed to the successful commercialization of biotech crops in Burkina Faso, Egypt, and South Africa.

THE IMPACT OF GM TECHNOLOGY IN AFRICA

Because there are only four countries in Africa that have commercialized GM crops, the evidence of the impacts of GM technology on the African continent draws mainly from a number of South African studies that document findings for cotton and maize and from ex ante reports that have estimated the potential benefits of different technologies in several African countries. These ex ante reports are based on a specific set of assumptions and models as outlined in Alston, Norton, and Pardey (1998) and also on innovative approaches, as in the case of Uganda studies on bananas (Kikulwe et al. 2010). The overall conclusion of these reports is that there are substantial gains from the adoption and use of the technology and that, compared to conventional crops, GM crops can mitigate yield losses and lead to reductions in pesticide applications. The results of the ex ante studies show that the adoption of GM crops in Africa can increase benefits for farmers and consumers (who in Africa are often one and the same) as well as agribusiness; this is consistent with evidence regarding GM crops in other adopting countries. The most striking conclusion from the analysis has to do with the impact of adoption time and delays on the realization of benefits. Time delays decrease the present value of benefits to both producers and consumers. Any lengthening of the R&D or regulatory time cycle results in real economic penalties in terms of advances in human welfare. Gross benefits will vary from country to country depending on the scale of production, the severity and physical extent of the target constraint, the local efficacy of the technology, the scale and speed of technology adoption by farmers, and the structure of local markets.

South Africa

South Africa first planted GM crops in 1996 with the commercialization of *Bacillus thuringiensis* (Bt, insect-resistant) cotton. Currently South Africa has also commercialized herbicide-tolerant (HT) cotton, which is both herbicide tolerant and insect resistant (HT/Bt); HT soybeans; and Bt, HT, and HT/Bt maize. There is a relatively substantial body of literature that documents and analyzes the adoption of the technology in this country—for example, a meta-analysis by Finger et al. (2011) that draws data from 58 biotechnology studies and a large analysis by Smale et al. (2009) of 18 journal publications.

The major body of literature on GM crops is about Bt cotton, probably because it was the first technology adopted. Finger et al. (2011) analyzed Bt and conventional performance data collected from all country reports, including those from South Africa. The vast majority of observations included in their analysis and in the literature comes from Australia, China, India, South Africa, and the United States. They conclude that there are statistically significant Bt effects on most of the performance variables considered. Bt cotton yields are about 46 percent higher than those for conventional cotton, and gross margins are also significantly higher (84 percent) despite the higher cost of Bt cotton seed relative to conventional seed. Their results also show lower pesticide costs and management costs for Bt cotton, although these are not statistically significant. They suggest caution in the interpretation of these data because the number of observations from India is large and there is great variability among and within countries.

To show this heterogeneity, Finger et al. present specific results by country (see Table C.1), including South Africa. In fact, the yield effect is significant only for India, although higher Bt cotton yields compared to those for conventional cotton are observed for all countries. This fact should not be misinterpreted. Bt technology is not primarily intended as a yield-enhancing technology; it is primarily intended as a damage abatement technology. Impacts on yield are secondary effects. What the numbers in Table C.1 confirm are the significant cost savings realized from a reduction in the use and cost of pesticide for South Africa, as well as the other two developing countries studied, due to the use of Bt cotton seed.

In a previous study, Smale et al. (2009) also suggested that the great variability across regions and within countries is, in large part, determined by the methods used. Particularly in South Africa, Smale et al. mention the need to take into account selection and placement bias and the variability in climatic conditions from one year to another. The findings of Ismael, Bennett, and Morse (2002) and Gouse, Kirsten, and Jenkins (2003) also show that small-scale farmers are the major overall beneficiaries of the technology, whereas those of Gouse, Pray, and Schimmelpfennig (2004) show that large-scale farmers in irrigated areas who used Bt seed gained the most in terms of yield increases and reduction of pesticide applications. Kirsten and Gouse (2003) and Shankar and Thirtle (2005) conclude that what small farmers gained in time from the reduced number of applications was lost in the additional time required to harvest the increased crop output. In short, one must consider constraints on the entire production system in interpreting these results.

Not reviewed by Finger et al. (2011) are the health and environmental effects from the reduced use of pesticides. Data from Bennett, Morse, and Ismael (2006) suggest that in South Africa the number of accidental pesticide poisonings has declined, and Morse, Bennett, and Ismael (2006) show positive environmental effects from the reduced use of pesticide.

Similar results have been documented for Bt maize. The scope and number of journal articles for Bt maize are smaller, which makes it more difficult to make generalizations. Smale et al. (2009) documented just 3 articles for Bt maize in South Africa, whereas Finger et al. (2011) recorded 12 observations. The relevance of a discussion about biotech maize in South Africa is that it was the first developing country to commercialize a GM food crop—Bt white maize. The results of the studies for the region, as analyzed by Smale et al., show that farmers who have adopted Bt maize have gained from increased yield when the Bt-targeted pests have been prevalent and have also benefited from a reduction of the time required to manage pests, as well as the reduced costs associated with labor for pesticide applications (Gouse et al. 2005, 2006).

Similar to the findings on Bt cotton, the data from a number of studies also point to positive health effects associated with the planting of Bt maize. A study by Shephard (2003) documents the alarming levels of aflatoxin contamination present in the African food supply. In 2010/2011 the International Food Policy Research Institute (IFPRI) undertook a project to analyze the impact of aflatoxin in African livelihoods, specifically on groundnuts in Mali and maize in Kenya (Unnevehr and Grace 2013) and published, among others, a paper that documents the health impacts of aflatoxin worldwide (Wu et al. 2011). Aflatoxin is a potent human liver carcinogen that is also associated with human stunting, immune system disorders, and negative effects on livestock and poultry health (Wu 2006a). Coarse grains such as maize, which are infested with pests, especially when stored under suboptimal conditions, are more prone to fungal (mycotoxin) infections, a primary source of aflatoxin contamination (Huesing and English 2004). Field studies of Bt maize show significantly lower levels of fungal infection compared to those for conventional maize (Munkvold, Hellmich, and Rice 1999; Wu, Miller, and Casman 2004). Because maize is a major staple crop of the African diet, limiting exposure to aflatoxin contamination can greatly minimize the accompanying negative health risks. Scientists are pointing to reduced risks from aflatoxin poisoning as an unexpected but highly desirable benefit from Bt maize, in particular, for African populations (Wu, Miller, and Casman 2004; Wu 2006a, 2006b).

The Rest of Africa

Aside from South Africa, Burkina Faso, Egypt (at least until 2012), and Sudan are the only other African countries that have commercialized GM crops. Probably because Burkina Faso first commercialized Bt cotton just a few years ago, there are few published studies that assess the effects of Bt cotton adoption in the country (Vitale et al. 2008, 2010). These studies document and analyze the effect the technology has had on farm performance indicators. A 2009 survey showed a significant increase in Bt cotton yields compared to those of conventional varieties (Vitale et al. 2010). As in other countries, significant variations exist across different producing regions. Vitale et al. conclude that the savings in pesticide application were offset by the higher cost of seeds. Similarly, labor savings from time saved by reduced pesticide applications were offset by increases in labor costs to harvest the additional output. But, overall, farmers saw an increase in their net earnings per hectare, mainly from the significant improvement in yields. As in any other region of the world that cultivates Bt cotton, the increase in yield was highly correlated with the relative level of pest prevalence.

The rest of the studies for Africa are all ex ante studies. Smale et al. (2009) reviewed five case studies in different countries of Africa. Four of these studies concentrate on the effect these technologies will have in the product market and quantify how the benefits will be distributed between farmers, consumers, and technology owners instead of focusing just on the impact for farmers.

One of the first studies of GM technologies for Africa is the one done by Qaim (2001) on virus- and weevil-resistant sweet potatoes in Kenya. The author projected that the adoption of the technologies would produce a gross annual benefit of US$5.4 million for virus resistance and US$9.9 million for weevil resistance, with producers capturing a great proportion (74 percent) of these benefits. Because these models are based on assumptions of key parameters (elasticity, adoption rates, patterns of adoption, costs of the technology), the author introduced some variation in these parameters to show that even under less optimistic scenarios the benefits of the technology would continue to remain relatively large. Unfortunately, this work was not continued in Kenya due to daunting technical challenges that required additional funding for further research that did not materialize.

The other four Africa-focused studies documented by Smale et al. (2009) are on Bt cotton in four West African countries (Cabanilla, Abdoulaye, and Sanders 2005), Bt maize in Kenya (De Groote et al. 2003), Bt cotton in West Africa (Falck-Zepeda, Horna, and Smale 2007), and Bt cotton and maize in Mali and other West African countries (Vitale et al. 2007, 2008). All studies show gains for producers and consumers; some are substantial, and others (Falck-Zepeda, Horna, and Smale 2007) are more conservative. What is clear from all of this research is that the timing of the technology is a crucial factor in the realization of benefits. The longer the time it takes to adopt the technology, the greater the loss in potential benefits.

In a 2006 report (Cohen et al. 2006) prepared by IFPRI for the Association for Strengthening Agricultural Research for Eastern and Central Africa (ASARECA) and COMESA, several GM technologies were evaluated. The overall conclusion of this report was that time delays associated with the delivery of productivity-enhancing technologies to farmers had significant welfare costs. The authors presented a payoff matrix approach that allowed analysts and investors to gain a quick overview of the costs of time delays, as well as the trade-off (in benefit terms) between the time-lag and productivity-enhancing attributes of R&D. R&D investment decisions, like investment decisions more generally, often involve weighing the possibility of modest short-term benefits against larger but more long-range benefits. Bayer, Norton, and Falck-Zepeda (2010) reached the same conclusion in their estimation of regulatory costs in the Philippines. Unnecessary delays in delivering GM technology will diminish the magnitude of welfare benefits and constitutes the most influential factor in determining the magnitude and variation of the technology's benefits.

Additional issues that require more careful analysis are consumer behavior and perception regarding GM technology. There is a more limited body of literature in this critical area, most of it arising from studies in China (Smale et al. 2009). However, a recent research report on consumer perceptions of GM bananas in Uganda (Kikulwe, Wesseler, and Falck-Zepeda 2011) provides some interesting insights. The study shows that consumers are willing to buy GM products priced the same as conventional products. This finding aligns with earlier studies done in Africa (Kimenju and De Groote 2008; Kushwaha et al. 2008; Bett, Okuro Ouma, and De Groote 2010). The study also shows that consumers' opinions regarding the acceptance of GM bananas are divided among distinct groups, with consumers more focused on health concerns and adopters more focused on environmental aspects. These revelations are important to note in the design of policies for the introduction of GM bananas in Uganda and GM crops more generally elsewhere.

Another salient conclusion of Kikulwe et al. (2011) and other researchers has to do with the dichotomy between the rural poor and the urban elite in terms of their support of or opposition to the technology. The fact that there is greater opposition to GM bananas among the urban elite lends some support to Paarlberg's (2008) hypothesis that African governments have been pressured by their urban elites to move toward a more precautionary approach to regulation. Paarlberg's analysis shows that urban elites are more likely to be influenced by groups opposing the technology, whereas those whose livelihoods may depend on the technology (that is, rural poor farmers) are fractionated as an influence group and often have little impact on the political or policy outcomes.

AN ANALYSIS OF THE TECHNICAL PIPELINE

Current Commercial Applications

In the 17 years since the first GM crop introduction, only 4 countries—Burkina Faso, Egypt (at least until 2012), South Africa, and Sudan—of the 54 countries in Africa have commercially released this technology. Currently South Africa is leading all other countries in the adoption of agbiotech. It first released Bt cotton in 1998 and then proceeded with Bt maize, HT cotton, and HT soybeans. It has also released stacked varieties (combining traits for HT and Bt) for maize and cotton. Further, it was the first developing country to release a food crop with the commercialization of white maize.

Despite the facts that cotton is a crop of enormous economic value to many countries in Africa and that production figures have been on the decline, the only two other countries in Africa that have commercialized GM cotton are Burkina Faso and, more recently, Sudan. Bt cotton was introduced to Burkina Faso in 2008, when cotton farmers planted 8,500 hectares with Bollgard II (Bt) varieties. By 2013 the total area in Bt cotton was 474,000 hectares that covered almost 51 percent of all area planted with cotton (James 2013). The 10-year process to gain commercial approval involved many local stakeholders and required the assistance of Monsanto to technically transfer the Bt gene to locally preferred varieties. The development and implementation of a regulatory framework was also a major hurdle that had to be overcome prior to commercialization (Vitale et al. 2010). Sudan started commercially producing Bt cotton in 2012, with 20,000 hectares planted.

The last of the four adopting African countries is Egypt, where a relatively small number of hectares were planted with Bt maize from 2008 until 2012. The area grew from the initial 700 hectares in 2008 to 2,000 hectares in 2012 (James 2012).

Potential Applications and Those under Development

The relevance of public-sector investment in GM technologies was initially assessed by an IFPRI-led project titled Next Harvest (Atanassov et al. 2004). The paper documenting it uncovered the important public-led research efforts in 16 developing countries in the development of 209 GM projects in 46 crops. Sithole-Niang, Cohen, and Zambrano (2004) used the results of this study to analyze the situation in Africa, specifically in Egypt, Kenya, South Africa, and Zimbabwe. The study showed that in these four countries the public sector was involved in 54 unique projects (crop-trait combination). The majority of these results were in Egypt and South Africa, with only 9 in Kenya and Zimbabwe combined. The study identified many bottlenecks in the development of these projects, from the lack of sufficient human and financial resources to less obvious ones such as the evolving regulatory hurdles imposed on GM crop development.

Table C.2 reflects an updated summary of biotechnology research projects in Africa. It is based on data from the 2004 Next Harvest study and an expanded data collection activity performed by IFPRI in 2005 (IFPRI 2005). Table C.2 also reflects additional data collected (via a desktop analysis) for the purposes of this report. The table does not indicate which projects have survived over time; there is a need to revisit the original data collected by Atanassov et al. (2004). However, a few points are obvious. South Africa is the overwhelming leader in agbiotech R&D, with projects in five crops and commercial releases of cotton, maize, and soybeans. Egypt follows in the number of GM crop research projects but is behind in the number of commercialized varieties. Today's situation, compared to the data for 2003–2005, shows an increased emphasis on some crops (cotton, maize, and cassava), whereas countries' interest across the continent has shifted from rice and cocoa to a variety of other crops (cucumbers, melons, squash, and potatoes). The lack of interest in cocoa is likely tied to chocolate industry concerns about GM and consumer acceptance, especially in Europe.

Of the current projects under development, four merit further examination for their importance to local economies, for their impact on key production constraints, and for the innovative ways in which they are being implemented. The first is Water Efficient Maize for Africa (WEMA), the second is Improved Maize for African Soils (IMAS), the third is African Biofortified Sorghum (ABS), and the fourth is Biofortified Bananas for East Africa. WEMA is a PPP of Monsanto, CIMMYT, the Kenya Agricultural Research Institute (KARI), the African Agricultural Technology Foundation (AATF), and a variety of research institutes from Kenya, Mozambique, South Africa, and Uganda. (See http://wema.aatf-africa.org/project-brief.) The goal of WEMA is to "make [drought-tolerant maize varieties] available to smallholder farmers royalty free through local African seed companies" (from the above website). The delivery of these technologies via public- and private-sector mechanisms could have important effects not only on adoption by small-scale farmers but also on the eventual productivity of the maize seed sector in the targeted African countries. WEMA is built on a working drought-tolerant trait provided by Monsanto. The WEMA trait is a well-characterized bacterial gene that has already been approved in the United States and is scheduled to be commercialized in the next two to four years. The next step is to evaluate the WEMA varieties and hybrid in confined field trials (CFTs) to test the performance of the transgenic plants. Incorporation of this trait into a range of African germplasm from various national programs will be required to realize the project's full potential and impact. Intellectual property hurdles are largely resolved because Monsanto has donated the technology. CIMMYT and the International Institute of Tropical Agriculture (IITA) will use it as a global public good (Cavalieri et al. 2011). CIMMYT (in collaboration with KARI in Kenya and the Agricultural Research Council [ARC] in South Africa) is also testing Pioneer's technology for nitrogen use efficiency in maize.

The IMAS project is a similar PPP aimed at dealing with soil infertility—a serious abiotic constraint that affects the productivity of many African farmers. Its technical goal is to use both marker-assisted breeding and GM technology to improve nitrogen use efficiency in varieties of African maize. The combined effects of increasing soil infertility due to poor soil conservation practices and the limited use of fertilizers are contributing to the low productivity of African soils.

The IMAS project is a partnership involving technology provided by Pioneer Hi-bred, royalty free, to small-scale farmers in Africa south of the Sahara (SSA) and involves institutional linkages between CIMMYT, KARI in Kenya, and the ARC in South Africa, which are working in collaboration with scientists at Pioneer to develop higher-yielding African maize varieties that use nitrogen more efficiently. The partnership, which is funded by the Bill and Melinda Gates Foundation (BMGF) and the US Agency for International Development (USAID) and is valued at about US$30 million, has a goal of producing varieties developed with conventional and marker-assisted technologies in a 4- to 9-year time frame and transgenic varieties in 10 years that will offer great benefit to address a number of soil fertility challenges in Africa.

The third interesting initiative is the ABS project, which will develop a more nutritious and easily digestible sorghum variety that contains increased levels of essential amino acids, especially lysine; increased levels of vitamin A; and more available iron and zinc. This project is expected to improve the health of a targeted 300 million people who depend on sorghum as a staple food in Africa. It is a multi-institution partnership leveraging the best of academic-, public-, and private-sector R&D expertise. (See http://biosorghum.org.)

The fourth project is Biofortified Bananas for East Africa, which is developing a GM high-iron, high–provitamin A banana. In West Africa, particularly Uganda, although bananas are the main source of calories, they do not provide the vitamin A and iron necessary to meet dietary requirements. To address this constraint, Queensland University of Technology (QUT) in Australia, in collaboration with the Uganda National Agricultural Research Organisation and Kawanda Agricultural Research Institute, as well as other partner institutes in Kenya, Tanzania, and the United States, has been working on the development of biofortified bananas since 2007. After completing CFTs for bananas biofortified with vitamin A and iron, researchers are now working on developing bananas with stacked iron and vitamin A. Fiedler, Kikulwe, and Birol (2013) have estimated the potential benefits of these biofortified bananas in Uganda, confirming that the project will be a very-cost effective health intervention, with a cost ratio of 16 percent and an internal rate of return of 31 percent. Finally, it is important to mention HarvestPlus, part of the CGIAR Research Program on Agriculture for Nutrition and Health. HarvestPlus is a global leader in the development of biofortified crops and now works with more than 200 agricultural and nutrition scientists around the world. (See www.harvestplus.org/content/about-harvestplus.) Although its work has focused on conventional breeding, a few upstream projects use GM techniques. The first, Nutritional Genomics for Micronutrient-Dense Cassava, intends to develop a provitamin A variety of cassava using the tools of genomics. The second is a project that uses transgenic technology to increase iron levels in African staple crops. The development of cassava with increased provitamin A, iron, and protein is another major project supported by BMGF. This work is being undertaken under the aegis of the BioCassava Plus (BC Plus) project in connection with the Donald Danforth Plant Science Center located in St. Louis, Missouri. (See http://www.danforthcenter.org/scientists-research/research-institutes/institute-for-international-crop-improvement/crop-improvement-projects/biocassava-plus.)

Gaps and Target Areas for Future Research

Up to now, commercialized GM technologies have been introduced for two relatively simple traits: insect resistance and herbicide tolerance. The focus has been mainly on commercial crops. As previously mentioned, a second generation of biotechnology traits and crops is under development that will address far more challenging and complex plant pathways and targets, such as drought tolerance, salt tolerance, and nitrogen fixation in the soil, all of which are important constraints affecting African agriculture. Although some of these have already been discussed, conventional breeding will continue to play an important and necessary role as a platform technology for GM technologies. It does not, however, offer the level of precision or expand the opportunities for novel gene introduction that are offered by the use of recombinant GM technologies. The tools of modern biotechnology offer an accompanying ability to transform preferred African varieties quickly, with efficiency, and in a way that is cost effective to address a host of future challenges. Regardless of the technology, it is important to note that consideration must be given to the market circumstances and value chain considerations that may ultimately affect the policies, success, and impacts of eventual products and vary from country to country and regionally across Africa.

Molecular breeding (including marker-assisted backcrossing, marker-assisted recurrent selection, and genomic selection) represents an opportunity to facilitate conventional breeding approaches in Africa because it improves selection efficiency, reduces the costs of developing new varieties that would not be subject to additional biosafety review (with introgressions of genes from the same species), and can be useful in maintaining quality control (for line purity and genetic identity). For certain traits, marker-assisted breeding may be technically more feasible than the introduction of traits via recombinant DNA technologies (that is, for complex traits involving many genes). Several projects in Africa are using molecular breeding technologies to develop improved varieties for drought tolerance, low nitrogen use, and insect and disease resistance. These projects (many of which are public-sector driven) are generating large public-sector datasets that could be widely applicable throughout Africa. In addition, as molecular breeding has advanced, the costs and efficiencies have become better optimized, permitting more engagement of members of the African breeding community, who are able to collect small samples and use regional hubs (such as Biosciences eastern and central Africa [BecA]) or commercial laboratories in the United States or Europe for genotyping analysis. The results of the externally generated analyses can then be used by local breeders, who analyze the data to make appropriate selections and decisions. Capacity building focused on this step and on molecular breeding in general could greatly enhance variety development by Africans using African germplasm without the level of controversy generated through GM technology for appropriate trait targets. As an example, the International Maize and Wheat Improvement Center (CIMMYT), working with 14 National Agricultural Research Systems (NARSs) in Africa, AATF, Monsanto, Pioneer, and Cornell University, has been taking this approach over the past three years in the generation of data for over 15,000 maize lines.

There are also important advances in livestock, fisheries, and forestry. The cloning of production animals that are resistant to specific diseases is just one example of GM in livestock. Cloning may also be important for breeding conservation and management strategies in the face of increasing ecological pressures (Juma and Serageldin 2007). The production of vaccines and making of diagnostic testing kits (the latter to diagnose disease-causing agents or to monitor the impacts of disease control programs) represent additional and important research areas for livestock. A number of advances are already under way. The International Livestock Research Institute (ILRI), headquartered in Nairobi, has a robust GM-based research agenda focused on a number of important diseases affecting livestock in Africa. Basic Research to Enable Agricultural Development (BREAD) is one of those projects. It aims to improve bovine health, especially for smallholder farmers, by using biotechnology for vaccine assessment related to foot and mouth disease. Programs that aim to reduce East Coast fever and African trypanosomiasis by the genetic bioengineering of cattle are other examples. A consortium of research institutes in South Africa, which includes the University of Pretoria, Utrecht University, Isogen Life Sciences, and the ARC–Onderstepoort Veterinary Institute, is working on diagnostic testing kits for tick-borne diseases. Similarly, a heat-stable recombinant rinderpest vaccine has been developed via a collaborative research effort between the University of California–Davis and Ethiopia's National Veterinary Institute. Finally, improvements in feed for better nutrition (such as improving the nutritive values of feed and forage or removing antinutritive elements) or animal digestion could offer great promise to the developing commercial livestock sector in Africa.

Despite the promising research agendas, the applications of biotechnology to address livestock productivity constraints are inadequate to address the numbers and variety of constraints affecting this critically important economic subsector. Excluding institutes in South Africa and ILRI, only a few national institutes, such as the Centre International de Recherche-Développement sur l'Elevage en Zone Subhumide (CIRDES) in Burkina Faso and the National Veterinary Institute in Ethiopia, are actively involved in livestock biotechnology research.

Opportunities also exist for fisheries via the improvement of fish feed for the aquaculture industry, which is important for Angola, Cameroon, Congo, Egypt, Ghana, Kenya, Madagascar, Malawi, Nigeria, Uganda, and Zambia, and as a natural resource management tool to better understand the genetics of fisheries populations.

Similarly, the tools of biotechnology could be important for the sustainable use and management of forestry resources. In contrast to the advances in commercialized GM crops that have experienced sustained growth since being introduced, GM trees have been commercialized in just one developing country—China—and represent only a few hundred hectares. China started planting Bt poplars seven years ago, and despite very positive reviews on the effectiveness and superior performance of these GM trees in controlling leaf pest damage compared to conventional clones, the area planted with these GM trees has not even reached 500 hectares (James 2012). There is growing global interest in this technology. Many other countries around the world have been performing research in this area. A 2004 report on the state of forest biotechnology prepared by the Food and Agriculture Organization of the United Nations (FAO) documented the existence of 520 GM forestry projects in 35 countries, with 16 countries conducting 210 field trials on GM trees (FAO 2004). Table 1 illustrates the geographical prevalence of GM forestry activities and the regulatory status reached by the different countries engaging in them. South Africa is the only country active in Africa, accounting for less than 1 percent of total global activity.

TABLE 1 Forest genetic modification (GM) activities around the world, 2010

GM ACTIVITY	REGIONS AND COUNTRIES			
	Africa	Europe	North and South America	Asia and Oceania
Commercial activities				China
Field experiments	South Africa	Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Netherlands, Norway, Portugal, Spain	Brazil, Canada, United States	Australia, India, Indonesia, New Zealand, South Korea
Laboratory activities		Italy, Sweden, Turkey	Argentina, Mexico	Japan, Malaysia, Thailand

Sources: FAO (2004); Verwer et al. (2010).

The potential benefits of GM forestry technologies are similar to those documented for GM crops, such as effective and novel ways to combat pests and diseases. But other potential benefits exist, including the ability to engineer and plant trees with specific characteristics for reforestation, regeneration, and afforestation. Molecular techniques and genomics to identify genetic diversity important for forestry management or to identify value-added traits for the wood, pulp, and paper industries are other promising avenues of research. Such activities could be especially important for Africa, where almost all cooking (an estimated 90 percent) is done with fuelwood and where pressure on this valuable and threatened resource is mounting (Agyei n.d.). Forestry projects could reasonably be attractive targets for public-sector investment given the potential societal and environmental benefits, but interesting PPPs could also be developed. This is especially true in light of the fact that recent years have seen a decline in the number of field trials from the public sector and an increase in those from the private sector (FAO 2004).

The 2004 FAO survey documented the perceived obstacles to the commercialization of forestry technologies and gave special emphasis to the lack of a regulatory framework that addresses trees and forestry products. Points that would require additional regulatory attention, in comparison to crops, would be the fragility of forestry ecosystems and the extended number of years a tree stands compared to annual crops, raising issues of regulatory control and management (FAO 2011a).

Finally, genetic engineering offers the possibility to broaden Africa's agriculture sector toward a platform that emphasizes manufacturing potential for products such as biofuels and pharmaceuticals. This will require an out-of-the-box look at GM technology by decisionmakers and a dialogue that expands the debate beyond the current focus on food and food security.

Genetic engineering will not, by itself, solve Africa's development problems. Nor will all available GM crops, traits, and other products always be useful or appropriate in the African context. But African decisionmakers should consider the benefits of genetic engineering as a tool within a portfolio of innovations and interventions that could potentially transform the African agriculture sector from its current state of poor performance to one that is of high value, has high potential, and is able to more rapidly respond to natural resource pressures and climate change. Additional data are needed to lend more robust credence to this possibility.

The Research Pipeline of CGIAR

CGIAR has 15 centers around the world and hosts more than 8,000 world-class scientists conducting research in more than 100 countries (Okusu 2009).[4] Conventional breeding comprises the vast majority of past and current scientific research conducted by CGIAR. Nevertheless, CGIAR has stated that it supports the use of GM technology in public goods research and is currently developing an updated biotechnology strategy.

CGIAR has estimated that just 3 percent of centers' research is "dedicated to the exploration of genetically modified organisms" (CGIAR 2011). Morris and Hoisington (2000) estimated that CGIAR spends US$25 million per year on biotechnology.

Okusu (2009) details all projects on transgenic research identified in a thorough survey on biosafety

4 CGIAR was formerly an acronym for the Consultative Group on International Agricultural Research; now it is simply CGIAR.

TABLE 2 CGIAR public- and private-sector genetic modification projects in Kenya, 2006

PROJECT	MAJOR PARTNERS
Insect-Resistant Maize for Africa (IRMA) Project	Kenyan Agricultural Research Institute (KARI), International Maize and Wheat Improvement Centre (CIMMYT), Syngenta Foundation
Evaluation and promotion of *Bacillus thuringiensis* (Bt) toxin–based biopesticides	University of Nairobi, Biotechnology Trust Africa (BTA), Dutch Government Ministry of International Development and Cooperation (DGIS), Kenyan Industrial Research and Development Institute (KIRD), KARI, International Center of Insect Physiology and Ecology (ICIPE), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Sweet potato and cassava tissue culture project for mass propagation of planting materials	KARI, BTA, DGIS, International Institute for Tropical Agriculture, International Potato Centre (CIP)
The development of drought-tolerant and pest- or insect-resistant maize varieties	KARI, BTA, DGIS, CIMMYT, University of Missouri–Columbia, Brookhaven National Laboratories

Source: Ayele, Chataway, and Wield (2006), Table 1.
Note: CGIAR was formerly an acronym for the Consultative Group on International Agricultural Research; now the group is simply called CGIAR.

and biotechnology implemented by the CGIAR System-wide Genetic Resources Program (SGRP) in 2008. We have reproduced Okuso's (2009) compilation in Table C.3. Although this table will need to be updated to provide a more precise picture of the past five years, it shows the focus of CGIAR's efforts on research projects that use transgenic technologies. Nine of the 15 centers are listed in Table C.3, with a total of 29 projects and 15 crops and a few noncrop initiatives. Most of these crops—cassava, cowpeas, groundnuts, pigeon peas, and bananas—are of economic importance to small-scale, resource-poor farmers in specific regions of the developing world. Despite the relatively small amount of money spent on biotechnology, CGIAR plays a crucial role in the development of these technologies for noncommercial subsistence crops, because there is little commercial gain for the private sector. To gain access to proprietary technologies for pro-poor biotechnology research, the CGIAR centers have participated in partnerships with the private sector and NARSs, including those in Africa. Ayele, Chataway, and Wield (2006) documented these projects for Kenya, as shown in Table 2.

There is no doubt that the private sector has led, and probably will continue to lead, the global biotechnology revolution. At the same time, CGIAR and public organizations have a responsibility to make these technologies available to resource-poor farmers. Interesting research efforts between new organizations in Africa (such as BecA) and various CGIAR centers (the International Potato Centre [CIP], IITA, CIMMYT) offer innovative models of collaboration in transgenic crop development (resistance to sweet potato weevils and banana bacterial wilt, to name two research targets) that are important to resource-poor, small-scale farmers. Yet figures published by Spielman (2006) show that in 2002 CGIAR's total expenditures on R&D (US$428 million) were less than Monsanto's US expenditures on seed biotechnology (US$500 million).

Although the private sector has developed and owns the great majority of the agbiotech tools (Spielman 2006), its interest, given its private nature, is in commercial crops. This is why CGIAR, despite its modest budget, has played such an important role in developing and providing expertise to enable biotechnology research on crops that are not of interest to commercial companies (Byerlee and Fischer 2002). The US$200 million that donors, CGIAR, and NARSs in developing countries invest in crops important to subsistence farming is "probably several times larger than private R&D directed at developing country needs" (Byerlee and Fischer 2002, 945). The situation may be changing, however; PPP projects (that is, drought-tolerant maize for Africa) exploit market segmentation differences and opportunities. This may encourage R&D investments that simultaneously benefit markets of varying value. In this case, one is likely to see greater investment on the part of industry, with substantial benefits realized for resource-poor or subsistence farmers in developing countries in addition to their wealthier commercial counterparts in industrialized countries.

Key Issues

BIOTECHNOLOGY CAPACITY IN AFRICA

Although the emphasis in this report is on biotechnology, a broad consideration of constraints to agriculture innovation in Africa is difficult to avoid in this discussion and provides much-needed context. In general, the reduced capacity in biotechnology and the continent's narrow ability to innovate in response to the demands of the new bioeconomy are results of many of the same underlying issues and constraints that have limited agriculture innovation in Africa for years. Africa's Science and Technology Consolidated Plan of Action (CPA), an initiative of the African Union (AU) and the New Partnership for Africa's Development (NEPAD), was developed to improve the quality of African science, technology, and innovation (STI) through regional networking and enabling policies. Biotechnology and biosciences are included among the five prioritized areas that are addressed in the plan, which focuses on three areas of concern: (1) research and development (R&D), (2) the policy environment and innovation mechanisms, and (3) funding and governance (Makinde, Mumba, and Ambali 2009). The 2007 AU/NEPAD report commissioned by a high-level biotechnology panel, *Freedom to Innovate,* provides a more detailed account of underlying policy and capacity constraints as well as recommendations to improve the current situation specific to biotechnology, some of which are also noted and endorsed in this report (Juma and Serageldin 2007). Transformation will require capacity improvements that reflect significant technical, policy, institutional, and financial change and resources.

Technical, Institutional, and Human Capacity

Technological innovations brought about by investments in R&D have contributed to poverty alleviation efforts in the past by attempting to reduce vulnerability and enhance or increase a community's asset base or its productivity (Falck-Zepeda et al. 2002; Adato and Meinzen-Dick 2003). Agricultural innovations have influenced—with different degrees of success—policies, institutions, and processes in rural communities and the development of alternative or better livelihood strategies for livelihood improvement.

One such agricultural innovation is the use of improved crop varieties, landraces, hybrids, and other plant genetic materials. Collectively, genetic materials conserved and used for breeding have been referred to as genetic resources for food and agriculture (GRFA) (see FAO 2001 and 2006 for the case of plants). These unique and diverse resources have been the backbone of improvement efforts related to crops, animals, and other organisms for centuries, since plant domestication began. New varieties and breeds are continuously derived from GRFA and are essential for agricultural improvement, just as they were during the Green Revolution, when production levels were greatly increased, as were food security and incomes for numerous farmers in the developing world (Evenson and Gollin 2003). Newer biotechnology techniques also rely on GRFA to ensure the transfer of valuable traits and benefits to poor farmers.

Farmers around the world can benefit from crops and animals that have a higher yield potential, increased productivity, and new sources of resistance needed to address evolving biotic and abiotic stresses, many of which result from agroecological patterns changing due to climate change. These adaptive genetic resources, especially on behalf of the poor, will require continued public and private investments in breeding that could be enhanced through the applications of modern biotechnology (Huang et al. 2002). Even so, the impacts of new products resulting from such research (including those that use biotechnology) may be increasingly hampered by a shift in R&D applications due to privatization and an inability of traditional systems to adjust to delivery requirements mandated by these new innovations, thereby compromising the impacts of innovation on the lives of poor farmers (Pingali and Traxler 2002).

Today's plant and animal breeders continue to face challenges similar to those of the past, including the need to create and deliver appropriate technologies. For some crops, conventional breeding can still account for 50–60 percent of yield increases (Duvick 1997; Fernandez-Cornejo 2004). Indeed, the continued important role of breeding should not be overlooked for the intrinsic innovation value it continues to offer and for its role as a platform technology for genetic engineering. But the use of genomics and genetic modification (GM) technology offers numerous options to reduce breeding times, add traits that are difficult to introduce with conventional techniques, capitalize on the biodiversity present in nature, and generate new varieties of plants and animals that are uniquely adapted to complex and changing ecosystems and market opportunities. With respect to the latter, the ability to customize and design crops through the use of biotechnology to meet the needs of specific value chains for specific commodities and particular geographies is a huge benefit offered by the technology. In this regard, it will be important to initiate discussions among regional economic communities (RECs) in Africa for the purpose of exploring research initiatives, products, best practices, and pitfalls (both technical and policy related) that may affect regional trade and regional productivity scenarios.

Although all of the aforementioned issues are important everywhere, the stakes are especially high in Africa given the current status of the agriculture sector across the continent.

Human resources

Plant-breeding capacity (as a platform for GM technology) and specialized capacity in molecular biology are limited in Africa relative to other developing regions (Southeast and South Asia, in particular). Inadequate national capacity in plant breeding, a platform technology for GM, is a hindrance to the production of high-quality seed, including biotech seed. Support to build the breeding capacities of national agricultural research systems is needed to fully capitalize on the benefits of agricultural biotechnology (agbiotech) (Daniel Otunge, AFSTA, pers. comm. December 2011).

Past efforts by donors were concentrated on building plant breeding capacity through long-term advanced degree programs. Until recently, these types of donor efforts were in decline as funding was directed toward other development sectors (health and population management). More recently a number of donor-funded efforts have attempted to deal with the recognized deficiencies in breeding and molecular biology capacities needed to drive sophisticated R&D advancements in agriculture. The Alliance for a Green Revolution in Africa (AGRA) is investing about US$35 million to support fellowships for aspiring men and women crop scientists and fund the curriculums of the local universities where they are trained (AGRA 2013). The government of Australia has provided funding to augment bioscience capacity in Africa through its support of the Africa Biosciences initiative (in particular the Biosciences eastern and central Africa [BecA] hub) with support focused on graduate, short-term, and hands-on workshop training in molecular biology. The African Women in Agricultural Research and Development (AWARD) program (http://awardfellowships.org), funded by the Bill and Melinda Gates Foundation (BMGF), the US Agency for International Development (USAID), and others, is providing support to bioscience capacity-building programs targeting African women.

The absence of biotechnology from school curricula also reinforces the concern about the lack of plant-breeding capacity, especially with regard to institutions of higher learning. This reflects a more endemic problem that has effects beyond those related to biotechnology capacity. Although several African universities have established degree programs in agricultural biotechnology at the MS and PhD levels (the BecA hub has been providing backstopping and training, and the Conference of African and French Leaders of Agricultural Research Institutes [CORAF] has been supporting this effort in West Africa), in more cases than not, African universities are not currently centers of science innovation. Malawi is one of the few African countries where science and technology policy is being implemented through the office of the head of state (Juma and Serageldin 2007).

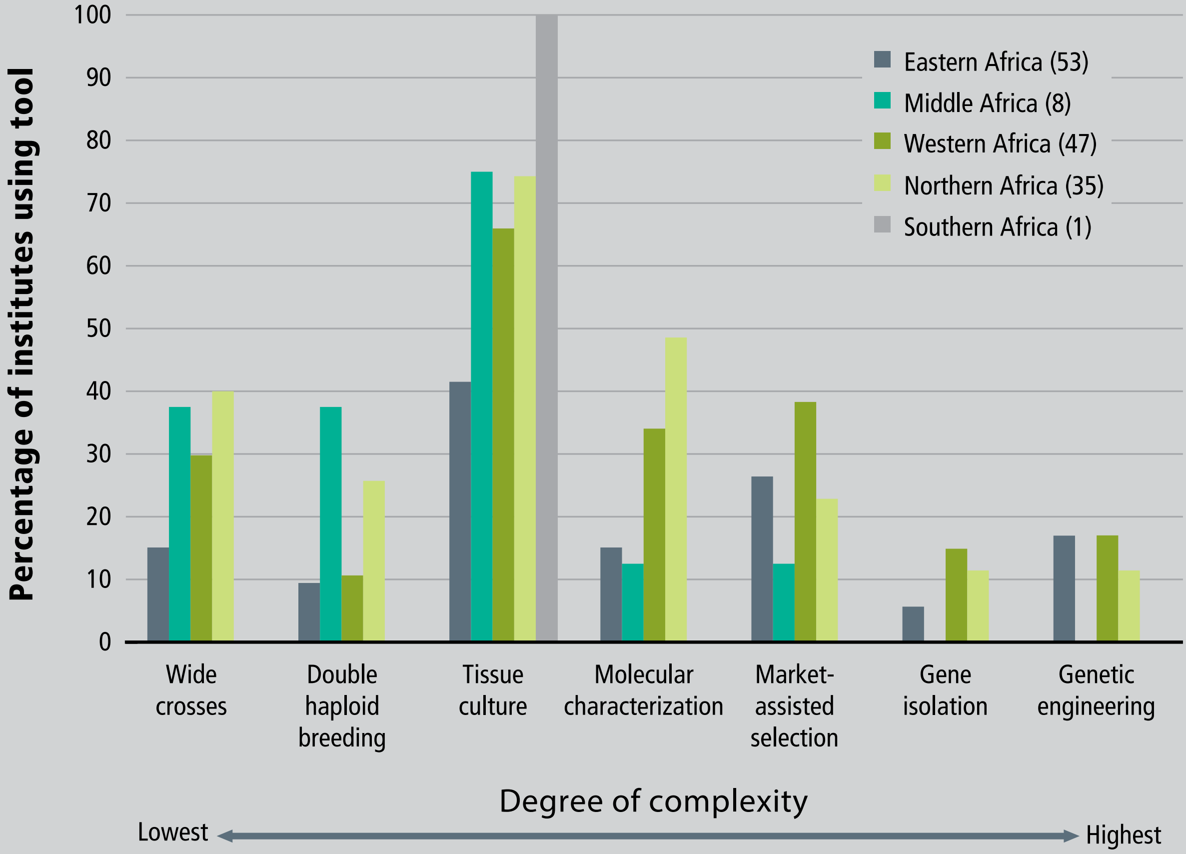
Despite these recent initiatives by mostly foreign donors, questions about the levels of capacity and the abilities of governments to retain qualified advanced staff remain. Breeders and molecular biologists continue to lack the physical and financial resources needed to fully drive biotechnology R&D. Donor efforts notwithstanding, African governments' own contributions to and priority setting for biotechnology funding and capacity building remain low. In the face of this situation, the lack of a critical mass of individuals with both advanced and lower-level technical skills will persist. Furthermore, the continual "brain drain" of talent to administrative duties, retirement, or better opportunities and more lucrative salaries abroad will likely threaten the new investments that are being made unless issues related to scientific enabling policies and infrastructure are addressed. The net result will be one of a continuing inadequate capacity of trained staff with the resources necessary to support a truly innovation-oriented science base for agriculture on the continent. Although the discussion here focuses on biotechnology, the reality is that these issues affect innovation throughout the agriculture sector and value chain, across many different disciplines.

Up-to-date centralized data that analyze the accumulated net effects of needs versus the new capacity-building initiatives that are being developed is lacking. A few studies have been conducted in the past that could be updated to provide a more current assessment of the situation.

The results of a study that attempted to assess the human capacity in Africa to conduct agbiotech research using data obtained from a survey by the Food and Agriculture Organization of the United Nations (FAO) and the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB) are presented in Table C.4. The table shows the number of plant biotechnologists and breeders in Africa by degree type and country. The total number of plant biotechnologists for all countries is 509, whereas the total number of plant breeders is 1,555. A breakdown by academic degree shows a fairly equal distribution among plant biotechnologists and plant breeders. PhDs account for 35 to 41 percent of the total number of professionals working in both areas. The number of PhDs available who could provide leadership is particularly important when considering human capacity requirements for biotechnology applications. Advanced degrees are required to understand and effectively apply advanced genetic transformation techniques. An analysis of the underlying data, which is not shown in the table (Guimaraes, Kueneman, and Carena 2006), revealed variations in the relative numbers of breeders versus biotechnologists as a function of time and resources. This may be due to an inability to consistently replace trained professionals who may be approaching retirement age. Donor and government investments in biotechnology trainers made during the late 1970s and early 1980s have not been sustained. The practical result is a diminished pipeline of trained plant breeders and biotechnologists who are able to conduct the needed research.

Although the total number of professionals involved in plant breeding or biotechnology research is important in order to formulate policies, it is equally important to understand the relative intensity of human resource availability. Table C.5 shows two distinct sets of resource-intensity indicators as measured by the human resources available per 100,000 hectares of arable land and per million inhabitants. Because there are no standards by which to measure whether countries are investing in an optimal way, these indicators, which show comparisons across countries and, when available, over time, provide some useful information about the relative situations in individual countries. In most cases, not surprisingly, the intensity of plant breeder availability is higher than that of plant biotechnologists in Africa. The methodology presented in these studies offers a quick assessment—a snapshot in

FIGURE 5 Biotechnology tools used in Africa, 2011 (percent use by the institutions surveyed)



Source: Compiled by authors from FAO-GIPB (2011).

Notes: The number in parentheses beside each region label represents the number of institutions surveyed in the region. (1) The data on Eastern Africa include data from Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda, Zambia, and Zimbabwe; (2) the data on Middle Africa include data from Angola, Cameroon, and Gabon; (3) the data on Southern Africa include data from Namibia only; (4) the data on Western Africa include data from Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo; and (5) the data on Northern Africa include data from Algeria, Morocco, Sudan, and Tunisia (in this figure, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan).

time—of capacity that could be used to provide a more current quantitative analysis of the situation or could be useful in evaluating the contributions of the various recent initiatives in capacity building.

The use of agriculture research methodologies and implications for identifying biotech capacity

Another method used to measure biotechnology capacity is to evaluate the technical methodologies, or tools, used by researchers. This type of analysis has limitations because there are no standard definitions for these tools, leading to speculation about their use and human competencies. Institutions may report the use of certain methods but without qualifications about competency, scale of use, or ability to move to more advanced methods. Analyses of this type are important because escalating to the use of more advanced tools implies a level of biotechnology sophistication and a greater ability, potentially, to deliver useful products. Other factors related to innovation (policies, markets, business climates, and so on) must also be considered in interpreting this type of data in order to effectively assess a country's ability to translate biotechnology research into useful products that reach farmers.

A regional analysis along these lines is shown for subregions in Africa in Figure 5. As expected, classical plant breeding methods and a few more basic biotechnology methods are used in all regions. The number of countries using increasingly sophisticated biotechnology methods is decidedly lower. These data are somewhat skewed because there were no data for Egypt and South Africa, which are both biotechnology adopters with good plant breeding and biotechnology skills.

Again, this type of study could be updated to obtain a more current analysis of the situation. When viewed in their totality, these data and analyses point to an obvious conclusion: currently, advanced training of African scientists in biotechnology (including plant breeders) has not been adequate or sufficiently prioritized over the years to fully realize the opportunities in agricultural biotechnology and to ensure global competitiveness. This means that if the current trends are not reversed, Africa will be unable to self-determine its research agenda for biotechnology. A comprehensive assessment and impact analysis do not currently exist to support these observations in the context of the more recent investment trends on the continent. Such an assessment would help make the case for additional resources with both national governments and donors. A few of the more notable capacity-building initiatives mentioned above are discussed below in more detail, and a focus on these could form the basis for a manageable analytical assessment to both quantify and qualify the impacts of these initiatives on more recent capacity-building efforts.

BIO-EARN. The Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN) was initiated in 1998 with resources provided by the Swedish International Development Cooperation Agency (SIDA). Its goal was to develop capacity in eastern Africa to use biotechnology for R&D in agriculture, industry, and environmental management. The first and second phases of the BIO-EARN program (1999–2005) were focused on building human and infrastructure capacity for research and biosafety. These phases were coordinated by the Stockholm Environment Institute (SEI) in collaboration with the Uganda National Council for Science and Technology (UNCST). Over a period of 10 years (1999–2009), the BIO-EARN program involved 35 institutions from Ethiopia, Kenya, Tanzania, and Uganda as well as Sweden; more than 100 scientists; and an even larger number of policymakers and practitioners from the region. The program has also developed new products, such as improved varieties of sorghum, cassava, and sweet potatoes, as well as new bioprocess technologies for wastewater treatment and energy production, and has served as a platform for regional collaboration and information sharing on biotechnology and biosafety policy issues.

Bio-Innovate. The Bio-resource Innovations Network for Eastern Africa Development (Bio-Innovate), a follow-up program to the earlier BIO-EARN project (1998–2010), was designed to target bioscience- and product-oriented innovation activities in eastern Africa (Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda). The program takes the innovative approach of trying to build a bridge between research output and biotechnology uptake. The total funding for this program (2010–2014) has been approximately US$11.5 million. Bio-Innovate has received private-sector contributions estimated at US$1. 9 million, although the initially expected financial support from or working partnerships with NEPAD, BecA, and other organizations have not materialized. The Bio-Innovate program has developed projects on targeted crops (sorghum and finger millets, cassava, potatoes, sweet potatoes, and beans) and other aspects of agriculture, such as agroindustrial waste management, waste treatment, and bioenhanced seeds. The program's focus has been on improved crop productivity and resilience to climate change in small-scale farming systems and on improved agroprocessing-industry efficiency in adding value to local bioresources in a sustainable manner. One of the main constraints on the program continues to be the apparent lack of demand from end users, suggesting that the products have not been demand driven (Crouch and Bloch 2013).

The African Biosciences Initiative. In 2005 the NEPAD Office of Science and Technology established the African Biosciences Initiative, which was charged with the creation of centers of excellence at hubs around the continent. A description of the hubs is given in Table 3 (Makinde, Mumba, and Ambali 2009). The long-term impact of this initiative represents a good organizational step to address the current human and institutional gaps in biotechnology. The West Africa Agricultural Productivity Program (WAAPP) has created subregional centers of excellence in Ghana (for roots and tubers), Mali (for rice), and Senegal (for sorghum). The Ghana center has a biotechnology facility, and similar facilities are planned for the others. A similar initiative is being supported under the East Africa Agriculture Productivity Program (EAAPP) in Ethiopia (for wheat), Kenya (for dairy), Tanzania (for rice), and Uganda (for cassava). The BecA hub, in particular, has been actively engaged in conducting transgenic research and providing services and capacity-building support to many institutions in Africa. It has strong capacity in the development of transgenics, genomics and functional genomics, metagenomics, bioinformatics, vaccines, and molecular diagnostics and provides DNA sequencing and genotyping services to institutions across Africa and

TABLE 3 New Partnership for Africa's Development (NEPAD) Office of Science and Technology (OST) networks of centers of excellence in biosciences, 2009

NETWORKS	NODAL POINT	NATIONAL HUB	CENTER'S FOCUS	AREA OF WORK
NABNet (Northern African Biosciences Network)	Egypt	National Research Center (NRC)	Biopharmaceuticals	North Africa: to lead the continent in research into biopharmaceuticals, drug manufacturing, and test kits
WABNet (West African Biosciences Network)	Senegal	Senegalese Institute of Agricultural Research (ISRA)	Crop biotech	West Africa: to carry out research using biotechnology tools to develop cash crops, cereals, grains, legumes, fruits and vegetables, and root and tuber crops
SANBio (Southern African Network for Biosciences)	South Africa	Council for Scientific and Industrial Research (CSIR), Bioscience Unit	Health biotech	Southern Africa: to deliver health biotechnology by researching the causes and methods of prevention of a range of diseases, in particular tuberculosis, malaria, and HIV/AIDS
BecA (Biosciences eastern and central Africa)	Kenya	International Livestock Research Institute (ILRI)	Animal biotech	East Africa: to focus on research into livestock pests and diseases in order to improve animal health and husbandry Central Africa: to build and strengthen indigenous capacity by identifying, conserving, and sustainably using natural resources and also researching into the impact on biodiversity of events such as climate change and natural disasters

Source: Makinde, Mumba, and Ambali (2009), Table 1.

elsewhere. Its headquarters are in a state-of-the-art facility on the campus of the International Livestock Research Institute (ILRI) in Nairobi, which features a Biosafety Level 3 (BSL-3) containment laboratory as well as lower-level and noncontainment facilities for tissue culture and plant transformation and greenhouses. Its impact on capacity building is reflected in recent statistics: between 2007 and 2011 a total of 133 African graduate students and 80 visiting African scientists acquired molecular biology skills and conducted research at BecA. Its research partnerships include advanced laboratories and institutions from Australia, Canada, China, Europe, Israel, South Korea, and the United States.

Research at African universities. An increasing number of African universities have developed curricula and degree programs for biotechnology and are becoming increasingly recognized as centers of biotechnology R&D, which represents a departure from past history, in which agriculture R&D was focused at national agriculture research institutes typically organized under ministries of agriculture. In South Africa alone, at least 16 universities or institutes of higher learning have biotechnology programs. Biotechnology R&D programs are also in place at a number of key universities throughout the continent, such as those in Egypt (at the University of Cairo, Ein Shams University, and Alexandria University), Ethiopia (at Addis Ababa University), Kenya (at Jomo Kenyatta and the University of Nairobi), Malawi (at Bunda College of Agriculture), Mauritius (at the University of Mauritius), Nigeria (at least six programs at institutions including the Universities of Ibadan and Jos), Uganda (at Makerere University), and Zimbabwe (at the University of Zimbabwe), to name a few. Nevertheless, most university programs remain poorly funded, lacking the equipment, supplies, trained staff, and operating funds necessary to conduct the more sophisticated aspects of GM research. Assessment of the capacity for research is hampered by the lack of a centralized database (even at national levels) that documents the current situation.

Gender Considerations

The majority of farmers in Africa are women. They provide 70–80 percent of the labor for food crops grown in Africa, and their importance to African agriculture and household-level food security cannot be underestimated. Clearly, improving agricultural productivity in Africa needs a gender focus, and this should include discussions about new technologies such as biotechnology and GM crops that are likely to affect women. In spite of the obvious, gender is possibly the most overlooked area when discussing agbiotech in Africa, despite the preponderance of women farmers and a growing number of women scientists, policymakers, and politicians. GM technology is considered highly technical; women, especially women farmers and other women stakeholders along the value chain, lack familiarity with it.

The available literature on the various constraints that limit the adoption of new technologies by women farmers has not included biotech crops in more than a limited number of studies. When impact studies of GM crop introductions are conducted, data are usually not gender disaggregated or the studies reflect a low percentage of female involvement or participation. What is known from the literature is that the technology has had mostly favorable responses from women farmers.

Bennett et al. (2003), in a study of *Bacillus thuringiensis* (Bt) cotton use in the Makhathini Flats region of South Africa, observed that a reduction in the number of sprays as a result of Bt cotton adoption freed up time for female farmers, with subsequent benefits for their entire families. Data about perceptions of Bt cotton in Bennett et al. (2003) are unfortunately not separated by gender, but they do mention that small-scale farmers (mostly women) grow Bt cotton because it is a labor-saving technology. The time-saving aspect of Bt cotton technology for women farmers is further mentioned in a later article using data from Bennett, Morse, and Ismael (2006). The authors also use company records from Vunisa Cotton of Makhathini Flats for the first three years of adoption to show that the majority of adopters were women. Thirtle et al. (2003) document that during the first planting season of Bt cotton in the Makhathini Flats most farmers who were offered Bt seed were men. In the second season, after seeing the success of the technology, women were more active in securing the seed so they could plant it.

Subramanian and Qaim (2009, 2010) present one of the more interesting conclusions related to the gender-differentiated impacts of Bt cotton. They show that the yields of Bt cotton increase as the number of female laborers participating in the production of cotton—mainly as workers hired for sowing, weeding, and harvesting operations—increases. In contrast, the expected reduction in the number of insecticide applications translates into less male family labor because pesticide application is done primarily by male family members. Income benefits, however, mostly favor males because they can use their free time in more productive (income-earning) activities off their farms, activities that are not generally open to women laborers (Subramanian and Qaim 2009, 2010).

In a study on the perceptions and experiences of women cotton farmers cultivating GM cotton in Colombia, Zambrano et al. (2011) find that women have favorable impressions about transgenic varieties of cotton compared to conventional varieties. The study, which has gender-disaggregated data, finds that both men and women farmers feel that transgenic varieties required less hired labor and less time for managing the crop. At the same time, some women and men farmers saw the former as a disadvantage, because hiring less labor would create more unemployment. The use of transgenic varieties also reduced seed wasting and allowed for better use of the available seeds for the available land. Planting machines helped reduce wasting, though poorer women farmers would generally not have access to these machines. Women farmers achieved better results with GM cotton because they followed the advice of the extension agents and thus had better returns from their investments. They also handled their credit lines better than did men.

However, women still faced constraints, including a lack of information about GM cotton and the technology and an inability to access labor-saving machinery. Their choice of varieties also differed from that of male farmers due to their emphasis on quality, time-saving attributes, and peace of mind, which factored into their decisions in addition to concerns about better yields. One of the surprising facts revealed by the study was the large number of tasks in which women were involved related to the sowing and harvesting of GM cotton.

Similar studies need to be conducted for women farmers in Africa. For countries that are in the process of making their decisions on commercializing GM crops, such studies could be ex ante. Studies need to include more comprehensive data on how women farmers view the technology and the factors that must be considered to enable their adoption of the technology. Studies also need to better examine impacts on household dynamics, children, and villages. Having ex ante data will enable researchers and policymakers to develop crop varieties that will be especially favorable for women farmers and could preemptively address gaps in policy and practice that could hamper the capacity of women to adopt these varieties even when beneficial GM crops are available.

Studies also need to be conducted in countries such as Burkina Faso, Egypt, and South Africa, which have already commercialized GM crops, to obtain gender-disaggregated data on GM crop impacts and to identify issues and constraints. Although some constraints (limited information, access to credit, inputs, assets, and extension services) will be common to women farmers in the adoption of any new technology, there may be some barriers to adoption that will be unique to GM crops. Unless comprehensive gender-disaggregated data are collected and analyzed, differences between male and female farmers will remain a matter of speculation and conjecture.

Changes to laws governing property rights are also needed to enable female ownership of land and property. Implementation and enforcement of these laws and policies are extremely important. These have a direct impact on the amount of investment women and households are willing to expend on more costly technological interventions, such as GM seeds. Legal awareness of such laws among women will be important in this regard.

A discussion about biotechnology and gender should not stop at the level of the farm. There is a need to mainstream gender considerations into all aspects of the discussion about biotechnology (Dr. Roshan Abdallah, Agricultural Innovation Research Foundation, pers. comm., December 2011). Gender impacts need to be considered with respect to business engagement, policy decisions, and scientific literacy and capacity building as well. Promoting collective action among women at various levels, from the farm through the various stages of the value chain, will enable women to gain from each other's experience and will also ensure that their voices are heard at decisionmaking levels. Zambrano et al. (2011) found that women turn to their informal networks for information and knowledge sharing. Hence, for those countries that wish to use the technology, it is also important to engage women's groups at the village level with information about GM technology.

In general, a harmonized gender position about agricultural GM technology is not evident in the national or international policy dialogue, and the potential impact of such a position on the debate has not been evaluated. A focus on gender with respect to biotechnology capacity building is a distinct recommendation of the AU/NEPAD High-Level Policy Panel on Biotechnology in its *Freedom to Innovate* report (Recommendation 10) (Juma and Serageldin 2007). A few initiatives have been started in response to this recommendation. The dismal statistics with respect to African women's education, their corresponding technological capacity, and their involvement in advanced scientific disciplines underscores the need to pay particular attention to this recommendation. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) estimates that only 45 percent of the women in Africa are literate compared to 70 percent of the men, 70 percent of African women do not complete primary school, and only about 1.5 percent of women achieve a higher education. Of all the disciplines, science and agriculture attract the fewest women, and women represent a very small percentage of African scientists and engineers (Juma and Serageldin 2007).

The lack of capacity building for women means that African countries are not capitalizing on a significant part of the workforce for potential innovation in agriculture. In contrast, in the United States the growth of agbiotech has led to increased opportunities for women in agribusiness and an increased presence of women in agriculture research programs that was not previously observed. The involvement of African women is needed not only to provide input into the technical focus of biotechnology research in Africa but to better inform the policy and political debate about issues that are directly important to and for women. Specific initiatives are required to turn the situation around.

One such example, which is not focused specifically on biotechnology but more generally on science leadership for women, is the AWARD program of CGIAR (www.cgiar.org/consortium-news/gender-and-diversity-a-time-for-change/) mentioned earlier. By all accounts, this three-year pilot program, launched in East Africa, has already been a success. AWARD is a professional development program that strengthens the research and leadership skills of African women in agricultural science, empowering them to contribute more effectively to poverty alleviation and food security in Africa south of the Sahara (SSA). Because AWARD fellows are scientists and are also involved in development policy, the AWARD platform could be used to facilitate better knowledge sharing between women scientists and policymakers about biotechnology.

Financial Capacity and Investment

Underinvesting in agriculture?

Despite the economic relevance of agriculture and its substantial contribution to the economies of most African countries, the proportion of public expenditures that governments devote to agriculture relative to other sectors of the economy appears to be declining over time. Data for 14 countries in Africa compiled by the International Food Policy Research Institute (IFPRI) as part of its Statistics of Public Expenditure for Economic Development (SPEED) database (IFPRI 2011) show that only two countries (Ethiopia and Zambia) have increased the percentage of their public expenditures on agriculture (Table 4). All others were proportionally spending less in 2007 than they spent in 1980, despite visible public commitments by Africa's leadership. Headey and Dorosh (2011) use the same IFPRI SPEED data to analyze the

TABLE 4 **Public agriculture expenditures, 1980–2007 (as a percentage of total expenditure)**

COUNTRY	1980	1990	2000	2007
Botswana	9.71	6.47	4.18	2.72
Egypt, Arab Republic	4.57	5.39	6.85	3.04
Ethiopia	7.02	6.88	6.60	14.36
Ghana	12.23	0.41	0.69	0.39
Kenya	8.28	10.19	5.48	3.42
Lesotho	8.02	9.79	3.68	3.19
Malawi	10.15	9.93	4.95	4.05
Mauritius	6.87	7.32	4.83	2.71
Morocco	6.46	5.26	3.18	2.01
Nigeria	3.03	5.12	2.05	1.97
Swaziland	12.98	7.26	6.61	4.42
Tunisia	14.52	9.56	9.26	5.95
Uganda	6.71	2.30	6.31	3.98
Zambia	—	2.82	6.54	8.33

Source: IFPRI (2011).
Note: Dash = data not available.

trends in public expenditures by sector in absolute values (in real US dollars) since 1980. Their analysis shows that agriculture sector expenditures have declined in absolute terms over the years in six of the seven countries analyzed: Ghana, Kenya, Malawi, Nigeria, Uganda, and Zambia. The liberalization policies of the International Monetary Fund (IMF) implemented in many of these countries may be contributing to reshaping budgetary allocations from agriculture to other areas of perceived greater priority, although this conclusion would need to be carefully analyzed. The relative power of the Ministry of Agriculture in relation to other ministries, particularly the Ministry of Finance, is also a possible explanation that merits exploration.

A similar scenario appears to be affecting the African Development Bank (AfDB) portfolio (Table 5). The Bank recognizes that agriculture is "critical to the continent's development and a key driver of poverty reduction" (AfDB 2010, 43) and has invested in key infrastructure and rural services projects, which are critical for agriculture. Although investments for agriculture declined from US$364.3 million, or 10.4 percent of all approved loans and grants in 2006, to US$103.4 million, or 1.9 percent of that total by 2010, in 2012 agriculture investments reached US$466.3 million, or 8.6 percent of all loans and grants, the highest percentage it has been since 2006.

The critical impact of this trend on African countries intending to use biotechnology for agriculture development has serious implications for future growth and development. Biotechnology R&D is a resource-intensive endeavor. As in the case of most research, sustained funding is needed over time to bring innovation to the marketplace. Investments in this technology require supportive financial structures and allocations, not just in the technology but also across the sector, to effectively capitalize to fully optimize the technology's impact.

With respect to specific investment in biotechnology, an accurate desktop analysis of the financial picture for Africa is difficult to achieve due to the lack of available and comprehensive information. Moreover, many new forms of financing apart from public or private research funding and public-private partnerships can be attracted for biotechnology funding in Africa. The availability of capital or debt investment funds for agriculture and

TABLE 5 African Development Bank (AfDB) group loan and grant approvals for agriculture, 2006–2012

DOLLAR VALUE OF GROUP LOANS AND GRANTS OR PERCENTAGE OF TOTAL	2006	2007	2008	2009	2010	2011	2012
Total (millions of US dollars)	3,492.8	3,907.7	4,797.4	11,358.0	5,560.5	6,246.7	5,452.0
Agriculture (millions of US dollars)	364.3	270.5	247.9	329.8	103.4	220.4	466.3
Agriculture (percentage of total)	10.4	6.9	5.2	2.9	1.9	3.5	8.6

Source: Benedict Kanu, lead agriculture expert, Agriculture and Agro-Industry Department (OSAN), AfDB, pers. comm., August 31, 2013. The original data are measured in the Unit of Account (UA) that the Bank uses. The exchange rate used for this table is 1 UA = US$1.51326 (August 2013).

agribusiness as well as venture capital funds presents new opportunities, hitherto unexplored, for financing agbiotech in African countries. Some information exists about the current landscape but not in sufficient detail to allow us to draw meaningful conclusions.

Trends in public-sector expenditures for plant breeding and biotechnology

Data from FAO-GIPB (2011) offer some insight into expenditures for agbiotech in Africa. The data are for only four years, and they are not complete for all countries or for all years. Nevertheless, some interesting trends can be identified. The database shows that plant breeding budgets for all African countries with available data have decreased dramatically, from 347 million 1993 international dollars in 1985 to 99 million 1993 international dollars in 2005. Although not indicative of biotechnology expenditures, these budget changes reveal diminishing financial support to the breeding platform that is needed to support biotech interventions.

Table 6 compares total financial resources and financial resources per researcher for plant breeders to those for biotechnologists from 1985 to the early 2000s. It reveals the overall funding situation in biotechnology and depicts whether individual research has sufficient financing to be effective.

The table shows data for two African countries, Cameroon and Kenya, measured against data for the Philippines (Falck-Zepeda et al. 2008). The results indicate that the total financial support for plant breeding has decreased in both Cameroon and Kenya. Support for biotechnology in Cameroon was low to begin with, but also declined from the 1990 levels. In Kenya the levels were higher than in Cameroon, but spending still decreased between 1990 and 2001. In contrast, these numbers increased for both plant breeding and biotechnology in the Philippines over the same period. Similarly, spending per researcher decreased for plant breeders in both Cameroon and Kenya from their levels in 1985. Kenya's spending increased until 1990 and then declined sharply. In contrast, the Philippines showed increases for both plant breeding and biotechnology spending per researcher. This is consistent with the high level of biotechnology performance outcomes in the Philippines compared to those in many other less developed countries, especially those in Africa.

Although these data are helpful, they are not indicative of the current situation in these countries because they are from 2001. Data need to be collected at the country level to update the dataset and allow us to understand the current trends in biotechnology research spending.

Table 7 presents a comparative regional analysis of agricultural African research budgets over distinct points in time. Overall agriculture research budgets declined across all regions except central and southern Africa (the latter represents only one data point, however). This is consistent with the general trends regarding decreased levels of support to agriculture research in the years leading up to the Maputo declaration of 2003. Again, the data available date back to 2005 with several missing data points.

More recent data: Spending on agriculture and agbiotech

Recent statistics on public spending in agbiotech are not available for most countries in Africa. Some data may have been collected by individual countries, but such data are not easily available. Public spending in agriculture R&D since the Maputo declaration offers a somewhat more optimistic picture and a step in the right direction. In 2011, countries south of the Sahara spent $1,692 million in agriculture R&D, an increase of more than 30 percent over the $1,208 million recorded in 2000 (Beintema and Stads 2014).[5] Spending was very

5 All spending figures in this section are measured in 2005 purchasing power parity dollars.

TABLE 6 Total financial resources and financial resources per researcher in select countries, 1985–2000s (thousands of 1993 international PPP dollars)

		FINANCIAL RESOURCES			FINANCIAL RESOURCES PER RESEARCHER	
COUNTRY	YEAR	Total	Plant breeding	Biotechnology	Plant breeding	Biotechnology
Cameroon	1985	20,212	4,589	231	169,967	76,942
	1990	5,880	905	403	18,091	23,687
	1995	15,977	1,030	208	26,399	10,383
	2001	27,145	1,050	218	27,643	12,122
Kenya	1985	15,138	9,096	736	232,640	171,242
	1990	32,070	18,068	2,837	426,123	497,673
	1995	14,210	7,927	1,337	159,825	252,263
	2001	13,629	6,773	1,634	129,744	259,380
Philippines	1985	12,059	8,982	280	91,653	23,317
	1990	18,281	10,907	1,371	79,038	57,135
	1995	26,209	10,952	2,562	79,940	88,333
	2000	57,068	14,896	6,608	117,293	254,172
	2004	149,219	21,619	7,808	196,532	260,275

Source: Falck-Zepeda et al. (2008).
Note: PPP = purchasing power parity.

TABLE 7 Agricultural research budgets in Africa, 1985–2005 (thousands of constant 1993 international dollars)

REGION	NUMBER OF INSTITUTIONS SURVEYED	1985	1990	1995	2000–2001	2003–2005
Eastern	44	243,662	96,267	84,975	107,543	94,587
Middle	8	3,051	2,649	1,678	128	2,496
Western	39	112,324	30,811	79,991	81,683	22,052
Southern	1	—	10,854	10,600	12,139	10,994
Northern	35	736,837	367,394	220,157	247,822	370,542
Total	127	1,095,875	507,974	397,400	449,314	500,671

Source: FAO-GIPB (2011) using the FAO classification of countries.
Notes: Dash = data not available. (1) The data on eastern Africa include data from Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda, Zambia, and Zimbabwe; (2) the data on middle Africa include data from Angola, Cameroon, and Gabon; (3) the data on southern Africa include data from Namibia only; (4) the data on western Africa include data from Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo; and (5) the data on northern Africa include data from Algeria, Morocco, Sudan, and Tunisia (in this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan).

uneven, however, with only 3 countries (Kenya, Nigeria, and South Africa) accounting for half of the spending and 2 countries (Nigeria and Uganda) accounting for half of the growth between 2000 and 2011 (Beintema and Stads 2014). The majority of African countries' annual national spending in public agricultural R&D has been between $10 and $50 million per year, with some spending less than $10 million (Beintema and Stads 2011). These amounts are less than 1 percent of these countries' gross domestic products (GDPs), a target set by NEPAD. Only 10 of the 40 countries in the Agriculture Science and Technology Indicators (ASTI) database had invested 1 percent or more of their GDPs in agricultural R&D in 2011 (Beintema and Stads 2014).

Actual spending on agbiotech is a fraction of the generalized spending on agriculture (less than $250,000 per year for most countries according to Mugabe 2002). As an example at the higher end of the spectrum, in Nigeria the National Agriculture Biotechnology Development Agency is providing $263 million per year in start-up funding for biotechnology. Specific data on such spending for Africa in its entirety is not well tracked.

Spending by private companies

The private sector is increasingly developing R&D solutions in crop biotechnology aimed toward small-scale farmers. In many developing countries, including South Africa (Box 1), both domestic and multinational companies are involved in private-sector R&D; this is less significant in most of the rest of the African countries. There are many well-known reasons: infrastructure in rural farming areas is inadequate, purchasing power is poor, seed markets barely exist, and there is a relative disincentive for private research that stems from the region's large number of different crops, each with a relatively small market (Ferroni 2010). Even in areas where private-sector investment in agriculture biotech research is robust, adoption is limited because of the absence of extension services and markets and also because the available technology is not well adapted to local conditions (Pray, Fuglie, and Johnson 2007). The price of seeds for GM crops developed by the private sector is higher than that for conventional seeds. Maneuvering the intellectual property (IP) landscape is also cumbersome for domestic and multinational private companies; this is a major disincentive to market entry for private companies that spend significant resources in R&D. Creative arrangements are needed to attract private biotechnology interests as a result of the negative policy and business factors.

Public-private partnerships (PPPs)

PPPs have become increasingly prevalent in many African countries. Such partnerships are a way to ensure that private research on GM crops is combined with local knowledge of varieties and cropping conditions that resides in public research organizations in order to develop GM crops suitable to African conditions.

Spielman and Grebmer (2006, 2) define a PPP as "any joint effort between public and private entities in which each contributes to planning, commits resources, shares risks and benefits, and conducts activities to accomplish a mutual objective." In Africa, an expected common goal of parties developing GM crops through PPP mechanisms is enhanced food security in the target country(s). R&D aspects of PPPs vary from country to country. Technology cannot be automatically transferred from developed countries to developing countries. Research on technologies involving inputs, genetic improvements of crops and soil, and water management systems requires a complementary approach to seed systems, agriculture extension, financial and infrastructure development, and market access (GCARD 2010).

In a paper that examined the PPPs in agbiotech in Kenya, Muraguri (2010) confirmed that most are relatively recent, donor driven, and time bound. They generally expire at the end of the funding period. Muraguri also contends that they are typically science led rather than demand or user driven, a point not necessarily affirmed by those involved. The public-sector partner is most often the dominant national research institute in the country. For example, in Kenya the Kenya Agricultural Research Institute (KARI) is the public-sector partner for most of these partnerships. Commercial companies generally donate the proprietary technology or genes and their scientific and market expertise. In Africa several interesting agbiotech PPP projects are under way to produce the following:

- Fast-growing, disease-resistant eucalyptus trees (tissue culture)—a partnership between Africa Harvest Biotech Foundation International (Africa Harvest), Monti (a South African company), and Gatsby Trust. Technology donation by Monti. Gatsby funded start-up costs.
- Tissue culture of bananas—a partnership between Africa Harvest, KARI, Du Roi (a South African company), Genetic Technologies Limited (Suresh Patel, Nairobi), the International Service for the Acquisition of Agri-biotech Applications (ISAAA), the African Biotechnology Stakeholders Forum (ABSF) (for public perception), Technoserve (a US NGO, for marketing), and DuPont (for funding).

BOX 1 Status of genetic modification approvals in South Africa, 2014

Significant attention has been focused on the technologies initially released by Monsanto in South Africa for maize and cotton. Yet other companies and public research organizations have been investing significantly in developing or transferring products in these and other crops. Private companies such as Syngenta, Pioneer (a DuPont company), and Bayer have submitted applications and received approval for confined field trials (CFTs) and commercialization in South Africa. The same can be said for public research and educational organizations such as the Agricultural Research Council–Vegetable and Ornamental Plant Institute (ARC-VOPI), the University of Natal, and the South African Sugarcane Research Institute (SASRI).

CROP	STAGE	RESEARCH ORGANIZATION	PRINCIPAL RESEARCHER	ORIGIN OF TRAIT BEING TESTED	NUMBER OF APPROVALS
Maize	CFTs	Syngenta	Syngenta	Syngenta	3
	CFTs	Pioneer	Pioneer	Pioneer	2
	Commercial	Syngenta	Syngenta	Syngenta	3
Cotton	CFTs	Bayer	Bayer	Bayer	10
	Commercial	Monsanto	Monsanto	Monsanto	4
Potatoes	CFTs	ARC-VOPI, Michigan State University (MSU)	Syngenta	US Agency for International Development (USAID), ARC, MSU	1
Soybeans	Commercial	Monsanto	Monsanto	Monsanto	1
Sugarcane	CFTs	SASRI	—	—	5
	CFTs	University of Natal	—	—	1
Wheat	CFTs	Monsanto	—	—	—

Source: FARA (n.d.).

Notes: Dash = data not available. Applications for experimental and contained greenhouse stages are excluded.

- Striga-free maize—a partnership between the African Agricultural Technology Foundation (AATF), the International Maize and Wheat Improvement Center (CIMMYT), KARI, and BASF (a German chemical company).
- Insect-Resistant Maize for Africa (IRMA)—a partnership between AATF, KARI, CIMMYT, and Syngenta Foundation.
- Vitamin A enhancement in maize—a partnership between the members of the HarvestPlus consortium: CIMMYT, IFPRI, the International Institute of Tropical Agriculture (IITA), the University of Illinois, Iowa State University, Wageningen University, and Monsanto.
- Genetic improvement of cowpeas—a partnership between the members of the Network for Genetic Improvement of Cowpea for Africa: Purdue University, the University of Zimbabwe, IITA, the University of California–Riverside, Michigan State University, the University of Virginia–Charlottesville, Kirkhouse Trust, and Monsanto.
- Virus-resistant sweet potatoes for Uganda—a partnership between Africa Harvest, Monsanto, KARI, Kenya Plant Health Inspectorate Services (KEPHIS), William Moar, and the University of Alabama–Auburn.
- Drought-tolerant crops—a partnership between the US Agency for International Development (USAID), the Rockefeller Foundation, the Partnership to Cut Hunger in Africa, CGIAR, and Winrock International.
- Cassava engineered for resistance to cassava mosaic disease (CMD) —a partnership between KARI, the Danforth Plant Science Center, USAID, Cornell University, ISAAA, and Kenyan universities.

- Bio-sorghum—a partnership between BMGF; Pioneer Hi-bred; national and international research institutes including KARI, the Agricultural Research Council (ARC), the Institut National de l'Environnement et des Recherches Agricole (INERA), the Council for Scientific and Industrial Research (CSIR), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and AATF; universities including the University of Pretoria and the University of California–Berkeley; and other organizations, including CORAF and Africa Harvest.
- Water-Efficient Maize for Africa (WEMA)—a partnership between AATF, KARI, the Instituto de Investigação Agrária de Moçambique (IIAM), the South African ARC, the Commission for Science and Technology (COSTECH), the National Agricultural Research Organisation (NARO), CIMMYT, and Monsanto.
- Improved Maize for African Soils (IMAS)—led by CIMMYT with BMGF as a funding partner. Other partner institutions are DuPont Pioneer Hi-Bred, KARI, and the South African ARC.
- Nitrogen use efficiency and salt tolerance technologies for use in African rice—a partnership between AATF, IITA, Arcadia Biosciences, USAID, and national partners (National Agricultural Research Organisations [NAROs]) in Burkina Faso, Ghana, Nigeria, and Uganda.

Box 2 gives a detailed view of one of these projects.

Investment funds and venture capital

Along with PPPs, there are also a number of investment funds (both private and public) that are targeting the agriculture sector in Africa. Investment funds pool capital and thus typically have greater resources than single investors. This is a very new phenomenon in African agriculture, with most of the funds having started in the latter half of the 21st century. In the infancy of their operations, these funds have usually operated in safe sectors with minimal risk, which excludes agriculture for the most part.

There is limited information about the involvement or use of these funds to support agbiotech research investments in SSA, although some are supporting agribusiness enterprises. This is not surprising because the entire value chain for biotechnology products targeting small-scale African farmers is problematic, from R&D to seed distribution, with South Africa a notable exception. Scale remains a huge issue because formal mechanisms for mass production of quality commercial seed are at a nascent

BOX 2 African Biofortified Sorghum (ABS)

The goal of the research-based technology component of the ABS project is to develop a transgenic sorghum that contains increased levels of essential nutrients, especially lysine, vitamin A, iron, and zinc. The nutrition-enhanced sorghum will be used by the product development team for introgression of the nutritional traits into high-yielding African and farmer-preferred varieties.

The ABS project's technology development group has seen close collaborations between Pioneer Hi-Bred (the principal technology donor), the Council for Scientific and Industrial Research (the technology recipient on behalf of Africa), and the University of Pretoria (which leads the nutrition and digestibility research). Their work involves developing and evaluating the set of technologies required to bring forth the ABS product, as well as creating the set of genes that will be transferred into the product during product development. As the project neared the end of Phase 1 (in June 2010), scientists from the three institutions worked on a product with the full complement of nutritional and digestibility traits.

The ABS project developed the world's first golden sorghum (with yellow or golden endosperm) as well as the world's first sorghum transformation system. Although the project had originally decided not to work on protein improvement, protein quality improved because the levels of the amino acids lysine, tryptophan, and threonine increased between 30 percent and 120 percent. Protein digestibility also increased with the reduction of kafirin proteins in the grain. Bioavailability, the absorption of iron and zinc in the digestive tract, was enhanced with the reduction of phytate molecules in the grain. Currently the group is working on increasing and stabilizing the levels of vitamin A within the plant.

Six successful sets of field trials of nutrition-rich sorghum have been conducted in the United States, where the sorghum has proven stable and effective over several generations. Although more than 70 scientists have been involved in this project, most of them in Africa, the technology development group is particularly proud of the capacity building of African scientists; this strengthens the south-north and private-public partnerships, ensuring that relationships are built on solid ground.

Source: Adapted from ABS Project (2014).

stage for most biotech crops in Africa, with the exception of cotton and maize.

To encourage inflow of private investment funds into agricultural value chains for GM crops, the seed systems need to be formalized and issues related to GM crop acceptance need resolution, because it will be difficult to maintain market segmentation of GM and non-GM seed in the fragmented African seed production system. Precautionary and expensive regulatory systems, consumer uncertainty, and trade disruptions for GM products are currently major obstacles for private fund investors.

Another form of investment that has not been exploited to fund biotechnology in Africa is venture capital. Essentially private in nature, venture capital refers to the provision of finance, managerial oversight, and strategic expertise to enterprises with novel, commercially viable ideas. Venture capital has catalyzed new business models and technologies to deliver novel, high-risk innovations in health in the developed world and has been an important source of funding for health and biotechnology companies (Masum et al. 2010). Venture capital was a primary funding source for many agbiotech companies in the United States in the early days of the industry (1980–1990s). A potential for high investment returns is an important criterion for attracting venture capital into a country. Although this potential does exist in a few African countries, few venture capital investments are supporting agbiotech enterprises in Africa. Data on venture capital spending in biotechnology in Africa are not readily available. Venture capital in Africa barely exists outside of South Africa and does not currently support the development of GM crops. Adongo (2005) identifies more than 155 private and public venture capital funds in 48 African countries. These funds are a mix of international and domestic venture funds from governments, donors, and the private sector. However, although some target agriculture, there is no clear identification of funds that specifically deal with agbiotech. A specific survey of venture capital funds operating in agbiotech in African countries would be a valuable undertaking to allow us to fully appreciate the potential impact (or lack thereof) of this funding. This may be a difficult undertaking, however, because information about venture capital fund portfolios are not usually publicly available. Also, tracking of quantitative information about the venture capital industry in Africa is a recent phenomenon, and there are only a few sources of information (such as the African Venture Capital Association Directory and the South African Venture Capital Association yearbook, which document and list the various venture capital funds).

With growing economic stability and deepening democracies in many African countries, this source of funding could be an important financing option for a nascent indigenous African agbiotech sector. However, because the existence of domestic enterprises in this sector is limited, support to develop an enabling business climate to attract venture capital funds will be needed.

South-South Collaboration

Increased trade between Africa and other emerging economies (Argentina, Brazil, China, India, and the Philippines, for example) offers interesting possibilities to explore the development of South-South R&D, capacity building, and policy relationships in biotechnology. Many of these countries have already commercialized a number of GM crops (Bt cotton, herbicide-tolerant [HT] soybeans, and Bt/HT maize, to name just a few). In addition, several are developing novel GM food, feed, and livestock products that may have specific relevance for many African economies, as are rice, beans, sugarcane, and bananas. The example of the Brazilian Agriculture Research Corporation (EMBRAPA) is an interesting one in this regard. EMBRAPA has a robust portfolio in agbiotech and an excellent history of public-private collaboration that could serve as a model for African R&D institutions. EMBRAPA established an Africa Office in Ghana in 2006 to assist, promote, and foster social development and economic growth through technology transfer and the sharing of knowledge and experience in the field of agricultural research. EMBRAPA Africa coordinates and monitors activities and projects in cooperation with African countries, interacts with governments and local authorities to determine priorities and needs, and interacts with EMBRAPA's headquarters and its research centers for the planning and implementation of projects and activities to deliver needed technical assistance. Examples of current training projects supported by US$2.8 million in funding from the Brazilian Cooperation Agency include those focused on cassava production or processing, cashew production, biofuels, conservation agriculture, and biotechnology. Additionally, US$1.35 million has been allocated for short-term projects and US$1.5 million for the implementation of a long-term project at the experimental station in Sotuba, Mali, to support the modernization and strengthening of cotton production. (See www.embrapa.br/a_embrapa/labex/africa/Escritorio_Africa.) In addition, BMGF is funding an initiative to strengthen institutional linkages between African and Brazilian institutions. (See www.africa-brazil.org.) Similar parallels and model initiatives could be pursued between African countries and high-level research institutes in Argentina, China, India, and the Philippines. Under the framework of the Forum on China-Africa Cooperation (FOCAC), China has pledged support for the construction of 20 agriculture technological demonstration centers, and the China-Africa Development Fund is considering a partnership with African development banks to expand investments in agriculture, which could include support for R&D. (See www.focac.org.)

In addition to collaboration on R&D, South-South collaborations in the areas of policy (biosafety, IP, and national capacity-building policies) would be useful to pursue because crop emphasis, challenges and constraints, and agroecological climates tend to be more similar than those of the United States, for example. Study tours for African regulators to India and the Philippines have already been implemented. Policy workshops in key areas (IP, biosafety, commercialization) could be developed, tapping into the expertise and experience of these emerging economies for Africa's benefit.

A Rapid Assessment of Agricultural Biotechnology Capacity in Africa

Measuring biotechnology capacity is not an easy task, especially because biotechnology innovations result from work in many applied disciplines (molecular biology, plant breeding, agronomy, and others). Furthermore, biotechnology innovation and capacity may be affected by the domestic and international innovation climate in general. Traditional indicators of technical capacity, such as expenditures and the number of human resources in a technology sector, can be considered only as a first step in the evaluation of biotechnology capacity. These indicators fall short of providing a full understanding of the complex biotechnology processes, policies, and abilities needed to develop advanced biotech inventions and products. In essence, estimators of biotechnology capacity need to assess the technical capacity to innovate, which may be constrained by institutional (regulatory and governance) and policy situations in each country in the region.

Other indicators, such as the number and type of biotechnology techniques and tools used or a country's capacity to effectively use IP protection, contribute to a better description of biotechnology capacity in a given country or region. These indicators must be used carefully, because they have many constraints, as discussed near the beginning of this section.

To fully understand biotechnology capacity in Africa, it is imperative to conduct a well-reasoned in-depth study that comprehensively assesses the R&D continuum that leads to the development of a biotechnology innovation or product. These indicators of biotechnology capacity need to be expanded to consider the multiple policy and regulatory issues that may constrain technology transfer, adoption, and use by farmers in developing countries. We have expanded the traditional approaches to measuring technical capacity to include some indicators of the institutional setting in which biotechnologies will be deployed.

With these caveats in mind, a rapid assessment of biotechnology capacity for Africa is offered here as a very preliminary prototype that could be more fully developed with adequate resources and a better mix of qualitative and quantitative data that are current and accurate.

Methodology

The rapid assessment outlined here is based on the Furman, Porter, and Stern (FPS) model for determinants of national innovative capacity described in a 2002 paper by Furman, Porter, and Stern. Because of the relatively steep data requirements of the FPS model, the analysis presented here is a simplification similar to those suggested by Fuglie and Pray (2000) and Trigo (2003). The objective is to perform a rapid assessment of African biotechnology capacity based on qualitative and quantitative indicators and to assess the factors for successful innovation. The analysis shows, not surprisingly, that countries with a higher level of national innovation tend to have more advanced biotechnology innovation systems. For details of the methodology and the approach, see Appendix B.

Data collected for each of the indicators listed in Appendix B were used to map each of the 56 African countries to categories measuring biotechnology capacity. To map countries to categories, we first estimated the percentage rank of the value for every single-country indicator. The percentage rank for each country's indicator value indicates its standing relative to other countries in the set. Second, in each country we took an average for each of the group of quantitative or qualitative indicators, such as overall innovative capacity, economywide status, IP situation, biotech capacity, and others. Finally, we aggregated the average percentage rank score for each group of indicators into one single-country qualitative score measuring overall potential for biotechnology innovation capacity as described in Table C.6. We then used the single percentage qualitative rank indicator in Table 8 to map countries, based on our expert opinion and additional information, into four categories: (1) nonselective biotechnology importers, (2) selective biotechnology importers, (3) biotechnology tool users, and (4) biotechnology

TABLE 8 Mapping countries to policy situations and policy objectives, 2014

POLICY SITUATION	POLICY OBJECTIVE TO FURTHER DEVELOP BIOTECHNOLOGY CAPACITY	SMALL MARKETS	MEDIUM MARKETS	LARGE MARKETS
Nonselective biotechnology importers	Develop the framework for using biotechnology products	Botswana, Cape Verde, Comoros, Equatorial Guinea, Gabon, Gambia, Guinea-Bissau, Lesotho, Liberia, Mauritius, São Tomé and Príncipe, Seychelles, Swaziland	Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Congo Republic, Côte d'Ivoire, Eritrea, Guinea, Libya, Madagascar, Malawi, Mali, Mauritania, Mozambique, Rwanda, Senegal, Sierra Leone, Somalia, Togo, Zimbabwe	Cameroon, Congo, Democratic Republic of Sudan, Niger
Selective biotechnology importers	Improve the efficiency of agricultural research through the use of biotechnology tools		Ghana, Namibia, Tunisia	Algeria, Ethiopia, Kenya, Morocco, Nigeria, Tanzania, Uganda, Zambia
Biotechnology tool users	Improve the efficiency and research and development of products			Egypt
Biotechnology innovators	Take advantage of the development of innovation capacity based on biotechnology applications and the development of innovations			South Africa

Source: Compiled by authors taking into account expert opinion and current institutional constraints.
Note: In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

innovators. This approach has been described by Trigo (2003) and Falck-Zepeda et al. (2008). Note that this simple procedure ranks countries relative to the only country on the continent that may now be mapped to the biotechnology innovators category—South Africa. This process is quite rudimentary because it uses averages and as such offers only a preliminary result. Data collection will need to be weighted based on perceptions and individual contributions to collective innovative capacity. Furthermore, there is no one-to-one correspondence between Table 8 and Table C.6. We have derived Table 8 from Table C.6 by using the results from Table C.6 and adjusting these results based on our expert opinion and other more current information about the status of biotechnology innovative capacity in the different countries in Africa.

To identify policy interventions and resources that might improve biotechnology capacity in Africa, it is useful to contrast capacity over time (past and present) against long-term government expectations and strategic plans. In-depth quantitative studies at the country level will be required to accurately do this. However, even the data in the preliminary qualitative analysis presented here will assist African countries to identify gaps, constraints, and weaknesses for each of the innovation categories (for example, overall innovative capacity, economywide status, IP situation, and so on) that affect the innovation system and may be making it inefficient, ineffective, or unresponsive to country needs. Evaluation of a country's innovation system can provide a good indicator of the country's future potential to innovate and a pathway for priority setting and strategy development to support this.

Results

The results of the qualitative indicator ranking analysis are presented in Table C.6. As noted previously, some of the qualitative scores presented here may not reflect the current situation in the country because they are based on a mix of current and past capacity. Results from the rapid assessment demonstrate a wide diversity among African countries in terms of overall innovative capacity, economywide status, IP situation, and the strength of the private sector and other indicators of national innovative capacity.

As discussed previously, we have used the quantitative and qualitative indicators to rank countries based on their national innovative capacity as presented in Table C.6. The limitations of using past and current data in this assessment may result in countries' being improperly ranked, especially in relation to immediate future prospects. The most important part of the analysis is to understand the individual scores in each category and the category's impact on the overall score. These data could be improved through in-depth national consultations and discussions. Nevertheless, this type of assessment can be used to identify gaps, limitations, issues, and potential avenues by which to develop biotechnology capacity, and it provides useful information about "potential" and priorities for would-be donors or investors.

We have further modified the assessment of countries' capacities in Table C.6, drawing on the authors' expert opinions to map countries' policy situations in Table 8. For example, although Egypt has invested significant resources in R&D and has developed multiple technologies, the institutional and policy environment has precluded the commercial deployment of any GM biotechnology in that country. In this strict sense, Egypt is a biotechnology tool user but cannot be classified as a biotechnology innovator. Egypt could graduate to the biotechnology innovator category in the near future if the country resolves current regulatory and institutional issues that may be limiting its biotechnology capacity development.

Nigeria, in spite of respectable investments in biotechnology, does not have the regulatory and legal framework necessary to deploy technologies commercially yet. Further work will be necessary to develop not only more technical capacity but also IP protection and seed systems, as well as to address other institutional and regulatory issues. Thus we have classified Nigeria as a selective biotechnology importer, but one with a real potential to move to the next category in the near future.

Other countries, such as Ghana, Kenya, and Uganda, demonstrate significant innovative capacity but are hampered by regulatory and policy issues that may be limiting their development of advanced biotechnology products. These countries may be able to selectively identify, directly transfer, or adapt biotechnology tools and technologies developed elsewhere for their own domestic use. Zambia and Zimbabwe have accumulated scientific and innovative capacity, but structural economic or regulatory policy issues may be hampering their potential advancement of biotechnology capacity in the near future.

One important caveat from the FPS model is that it focuses on innovation and thus fails to describe the process by which products and technologies move from the laboratory into farmers' hands. This is a major limitation of this approach. Linking upstream biotechnology innovations to downstream product development or commercialization interests is important to understand the policy gaps and needs.

In the specific case of plant breeding and biotechnology, the seed systems used to deliver GM technologies to farmers matter quite significantly. In fact, papers by Atanassov et al. (2004) and Cohen (2005) argue quite strongly that most public-sector institutions have not yet been successful in transferring GM crops to farmers. Significant investments are needed to transfer the technology to farmers in terms of regulatory approvals, postrelease monitoring, transmitting information to farmers on how to use the technology, and so on, and these need to accompany the technology to maximize its value to farmers. (See Tripp 2009 and Falck-Zepeda 2006 for a similar argument.) Public-sector institutions need to find alternative strategies to deal with this new technology transfer environment, which puts additional pressure on budgets and the costs of doing business; this is an area worthy of additional study.

REGULATORY POLICY

Status and Capacity

General principles

A sound legal framework is necessary to inspire trust in a government's ability to regulate biotechnology—to minimize the risk, maximize the benefit, and ensure public confidence. This is true not only for biotechnology but for any new technology (Paarlberg 2001). Many options exist for the creation of policies and structures that govern the introduction of biotechnology products. Regulation could be established under existing laws and agencies or created de novo, with implementation responsibility accorded to a new regulatory body or agency or to existing regulatory bodies (Wafula et al. 2012). The type of regulatory approach adopted is generally determined by a combination of a country's need for or perception of the technology combined with other complicating factors, such as trade. Paarlberg (2001) classifies regulatory approaches into four different categories, shown in Table 9. Approaches vary along a gradient of opinion about whether the process of biotechnology is inherently risky, and they reflect the product-versus-process debate.

Questions of safety

GM crops were first introduced into commercial agriculture in the mid-1990s and have since been planted on millions of hectares of farmland on every continent except

TABLE 9 Biosafety policy options in Africa, 2001

PROMOTIONAL	PERMISSIVE	PRECAUTIONARY	PREVENTIVE
No careful screening; only token screening or approval based on approvals in other countries	Case-by-case screening for demonstrated risk based on intended use of product	Case-by-case screening for scientific uncertainties as well as demonstrated risks owing to the novelty of the genetic modification (GM) process	No careful case-by-case screening; biosafety risk assumed because of the GM process

Source: Paarlberg (2001).

Antarctica. To date, there has been no *scientifically documented* evidence of human or environmental harm. Prior to commercial release, independent experts in human and animal nutrition and toxicology, as well as specialists in environmental safety, review large volumes of data to ensure the safety of these crops. Some have argued that biotechnology is the most regulated technology in the history of agriculture. A large number of national and international scientific organizations around the world have attested to the safety of GM technologies, including the following:

- The Food and Agriculture Organization
- The World Health Organization
- The Organisation for Economic Co-operation and Development
- Asia-Pacific Economic Cooperation
- The Royal Society of London
- The German National Science Foundation
- The Brazilian Academy of Sciences
- The Chinese Academy of Sciences
- The Indian National Science Academy
- The Mexican Academy of Sciences
- The World Academy of Sciences
- The National Academy of Sciences (United States)
- The American Society of Microbiology
- Patrick Moore (the founder of Greenpeace)

Despite the findings of these internationally recognized experts, reports to the contrary continue in Africa. Questions about antibiotic resistance, allergenicity, toxicology, genetic pollution, pollen flow, loss of biodiversity, effects on nontarget organisms, an increase in weedy species, sterility, and obesity are consistently raised at all levels of African society. This uncertainty is reflected in the state of African regulatory systems. An examination of the current, and seemingly ineffective, *methods, messengers, and approaches* used to convey safety data to policymakers and the public in Africa is sorely needed.

The situation in Africa

African regulatory systems are products of the ongoing tensions associated with biotechnology. Many African countries currently favor the precautionary approach, which has been greatly influenced by the position of the EU and the Cartagena Protocol on Biosafety (CPB). The risk-averse stance exhibited by many African governments may be traced to a premature discussion of regulatory regimes during the CPB process, which preceded, by many years, the actual and practical experience of African governments with new GM crops. The CPB has become the driving regulatory force in Africa, setting the standard for national legislation; its legacy persists today. Specific, especially contentious, policy issues raised by the CPB are discussed later in this section.

The current regulatory situation in Africa is best characterized as

- confused and disaggregated (in terms of approach),
- lacking in capacity and therefore technically weak and generally inefficient,
- lacking in transparency and procedural rigor,
- unable to meet a local test for affordability, and
- overly influenced by politics stemming from
  - its historical trade relationship with Europe,
  - traditional and culturally accepted practices of crop cultivation, and
  - the absence of a market-driven approach to agriculture, which places an extreme burden on national governments (and their regulatory systems) to address and guarantee food security.

Many have argued that the lack of functional, efficient, and technically competent regulatory systems in

TABLE 10 Status of biosafety policies and legislation in Africa, 2014

STATUS OF POLICIES OR LEGISLATION	COUNTRIES
Enacted biosafety laws or regulations	Burkina Faso, Cameroon, Ethiopia, Ghana, Kenya, Libya, Malawi, Mali, Mauritius, Namibia, Senegal, South Africa, Sudan, Tanzania, Togo, Zambia, Zimbabwe
Drafted biosafety bills	Algeria, Burundi, Côte d'Ivoire, Democratic Republic of Congo, Eritrea, Guinea-Bissau, Madagascar, Morocco, Nigeria, Rwanda, Seychelles, Swaziland, Tunisia, Uganda
Approved biotech or biosafety policy	Cameroon, Kenya, Madagascar, Malawi, Namibia, Seychelles, Sudan, Swaziland, Uganda, Zambia, Zimbabwe
Drafted biotech or biosafety policy	Comoros, Democratic Republic of Congo, Eritrea, Rwanda
Developed sectorial legislation with reference to biosafety	Egypt
Developed sectorial biotech or biosafety policies with reference to biotech and biosafety	Djibouti, Egypt, Ethiopia, Mauritius, Seychelles

Source: Wakhungu (2009); updated by John Komen, Program for Biosafety Systems assistant director, pers. comm., 2014.
Note: In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

most African countries is currently the major constraint limiting the rate of adoption of biotechnology and GM products, whether these products are generated internally or externally, by the private sector or the public (Adenle 2011). Africa is not unique in this respect. The EU's highly precautionary system has also stymied progress in agricultural biotechnology in Europe, with impacts on both public and private research institutions. Many other developing countries are also struggling with regulatory policy. However, food insecurity, climate change, and natural resource vulnerability create unique pressures on Africa to resolve its current regulatory dysfunction, move to a position of balance, and build local capacity to handle the technology. This point was recognized by the AU/NEPAD High-Level Panel on Biotechnology in Recommendation 12, which states, "Africa needs to develop its own scientific capacity to assess biotechnology-related risks through national, regional and continental institutions so that all biotechnology policy is informed by the best available research and knowledge. The consensus among researchers thus far is that there is no compelling evidence of harm from the consumption of approved foods and food products manufactured from biotechnology processes" (Juma and Serageldin 2007, 115).

Laws and guidelines

A byproduct of the CPB for African regulatory systems has been a capacity-building initiative implemented by the United Nations Environment Programme–Global Environment Facility (UNEP-GEF). To meet the obligations of the protocol, UNEP-GEF provided resources (technical and financial) to get countries to ratify the development of national biosafety frameworks (NBFs) and national focal points to preside over the regulatory system. Project goals were to assist countries in the development of (1) a policy on biotechnology, (2) laws and regulations on biosafety constituting a regulatory regime for biotechnology, (3) an administrative system for handling applications and issuance of permits, and (4) a mechanism for public participation in biosafety decisionmaking (Makinde, Mumba, and Ambali 2009). By the end of June 2011, 48 of the 54 countries in Africa had ratified or complied with accession requirements of the CPB, in part due to the UNEP-GEF initiative. (See http://bch.cbd.int/protocol/parties/.) An overview of the policy development picture in Africa is shown in Table 10.

The UNEP-GEF biosafety program was one of the early biosafety capacity-building efforts in Africa. Given its focus on ministries of the environment, it stands to reason that significant regulatory authority for biotechnology in Africa today rests with these ministries despite the crosscutting nature of the technology. Environment ministries generally favor a precautionary approach. The result, argued by some, is a functional disharmony among African regulatory bodies about what constitutes a reasoned regulatory approach. As the situation has evolved, more countries have expanded their regulatory authority to include shared or primary responsibility with other ministries, including those for higher education, science and technology, agriculture, health, trade, and industry. When other ministries are involved in the regulatory framework, a more balanced approached to regulation generally prevails. Nevertheless, intra- and interministerial roles and responsibilities remain unclear in most African countries. A process-mapping approach to regulatory frameworks could be a useful tool to eliminate confusion and redundancy in regulatory systems.

Policy into practice

Despite the progress in developing legal frameworks in Africa, translating policy into practice has been slow and laborious. As mentioned earlier in this report and depicted in Table 11, the commercialization of GM crops is confined to just four countries—Burkina Faso, Egypt (until 2012), South Africa, and Sudan. Six other countries (Ghana, Kenya, Malawi, Nigeria, Uganda, and Zimbabwe) have confined or multilocation field trials in place. An approval to test Bt cotton was granted in Malawi in 2012, a confined field trial (CFT) was carried out in 2013, and multilocation trials are currently under way. Uganda is quickly moving toward commercialization but has not yet passed a national biosafety law, and this may stall progress.

Several countries have national laws in place but are not yet in a position to conduct CFTs. This is the case of Ethiopia, Tanzania, and Zambia, in particular. This may be due either to laws that are highly restrictive or the presence of a nonpermissive sociopolitical environment.

Capacity-building initiatives

Beyond the UNEP-GEF effort, which has now ended, additional capacity-building efforts have been launched to develop regulatory frameworks and to build capacity for decisionmaking, monitoring, and enforcement. A partial sampling of biosafety capacity-building initiatives in Africa is shown in Table 12.

Among these, two programs, the Program for Biosafety Systems (PBS) and the African Biosafety Network of Expertise (ABNE), have signed a memorandum of understanding to build better coordination and complementary efforts. PBS is managed by IFPRI and is one of the oldest (since 2003) biosafety capacity-building programs still active on the continent. It is also active in Southeast Asia, thereby offering possibilities for South-South cooperation and exchange. It is funded by USAID and has a national, regional (Common Market for Eastern and Southern Africa [COMESA]), and international (CPB) focus. Its objective is to empower African countries to develop, implement, and manage their own systems by providing training, technical and legal advice, and independent policy research for decisionmakers. Its approach provides a constant in-country presence with an ability to directly interface with African governments. PBS has helped to establish CFTs in Kenya, Nigeria, and Uganda; has developed policies and aided the passage of biosafety laws in Ghana, Kenya, Malawi, Nigeria, and Uganda; and has developed tools for strategic and systematic outreach to create awareness among stakeholders. (See http://pbs.ifpri.info.)

ABNE is supported by BMGF in collaboration with Michigan State University and works under the auspices of AU/NEPAD. It was created in response to the need to develop African capacity to assess *whether, when,* and *how* biotechnology products may be adopted. It focuses on (1) building an African biosafety resource for regulators with an emphasis on members of the national biosafety committees, institutional biosafety committees (IBCs), and plant quarantine agencies, and (2) providing long-term support to build functional regulatory systems (Makinde, Mumba, and Ambali 2009).

PBS and ABNE are working together to consolidate and organize capacity-building work plans and, in some cases, are jointly funding activities, and training and annual coordination meetings with other service providers have been in place since 2011. This type of cooperation and consolidation of effort are good first steps, but more comprehensive efforts are needed in Africa to minimize the conflicting messages about biosafety originating from regulatory support programs funded by donors with varying philosophies about the technology.

Nonetheless, capacity-building efforts are beginning to have an impact. In the past five years, more countries have

- initiated CFTs with GM crops,
- passed biosafety laws and implemented regulations,
- begun to address the need for stakeholder outreach and awareness,
- involved local scientists in regulatory decisionmaking,
- begun harmonization activities, and
- recognized the need to engage the political process to achieve results.

Despite the positive trends, regulatory disparity still exists across Africa. Additional resources and expertise will be needed to resolve some of the ongoing issues and gaps. Specific topics requiring attention with the use of additional support are as follows:

- Risk assessment requirements that are not timed appropriately to the product development cycle.

TABLE 11 Policy to practice: Confined field trials (CFTs), commercial releases (CR), greenhouses (GH), and transformations (TR) in selected countries, 2014

CROP	BURKINA FASO	EGYPT	GHANA	KENYA	MALAWI	MOZAMBIQUE	NIGERIA	SOUTH AFRICA	SUDAN	TANZANIA	UGANDA	ZIMBABWE
Bananas											CFT	
Canola								CR, CFT				
Cassava				CFT			CFT	TR			CFT	TR
Cotton	CR, CFT	CFT	CFT	CFT	CFT	~CFT		CR, CFT	CR		CFT	CFT
Cowpeas	CFT		CFT				CFT					
Maize		CR, CFT		CFT		~CFT		CR, CFT		~CFT	CFT	~CFT
Pigeon peas				TR/ GH								
Potatoes		CFT						TR				TR
Rice			CFT								CFT	
Sorghum	CFT			CFT			CFT	TR				
Soybeans								CR, CFT				
Sugar-cane								CR, CFT				
Sweet potatoes			GH	CFT							GH	
Tobacco										CFT		
Tomatoes		GH										
Wheat		CFT										

Source: Compiled by authors from information detailed in Appendix A.

Notes: ~CFT indicates that a trial has been approved or a mock trial has been conducted. In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

TABLE 12 A sampling of biosafety capacity-building programs active in Africa, 2009

INITIATIVE	KEY PLAYERS	ACTIVITY OR OBJECTIVE
United Nations Environment Programme–Global Environment Facility (UNEP-GEF)	All African countries	Promoting biosafety in conformity with the Convention on Biological Diversity (CBD)
International Centre for Genetic Engineering and Biotechnology (ICGEB)	African countries south of the Sahara	Strengthening and expanding biosafety systems
Program for Biosafety Systems (PBS)	Common Market for Eastern and Southern Africa (COMESA), Ghana, Kenya, Malawi, Mozambique, Nigeria, Tanzania, Uganda	Providing integrated practical technical, legal, and outreach or communications expertise to assist African countries in the creation of functional biosafety systems and approaches
African Biosafety Network of Expertise (ABNE)–New Partnership for Africa's Development (NEPAD)	All African countries	Empowering Africans to develop and implement biosafety frameworks
Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety, and Biotechnology Policy Development (BIO-EARN)	East Africa	Promoting biosafety in research and development
Forum for Agricultural Research in Africa (FARA)–African Biotechnology and Biosafety Policy Platform (ABBPP)	All African countries	Promoting biosafety policy dialogue among diverse stakeholders at all decisionmaking levels—national, regional, and continental

Source: Karembu, Nguthi, and Ismail (2009).

- Overlapping ministerial jurisdictions and lack of clarity regarding decisionmaking roles and authority.
- The impacts of limited funding for regulatory operations related to decisionmaking, independent review, and the ability to use the technology.
- Disconnects between biosafety laws and other preexisting legislation.
- Raising awareness within governments about the expensive nature of their current systems and the impacts on local R&D institutions (including the inability to afford their own systems, leaving only multinationals with the ability to meet regulatory and compliance protocols).
- Creating awareness among regulators about the need for regulatory flexibility and the importance of limiting technical requirements and specificity to implementing regulations, as opposed to national law, in order to permit expeditious adjustments to regulatory systems as the science evolves.
- The persistence of strict liability clauses in regulations that are disincentives to R&D, investment, and technology transfer.
- Resolving confusing and contradictory messages from diverse service providers.
- Creating additional understanding about the steps involved in moving from CFTs of GM crops to deregulation or commercialization in order to get products in the hands of farmers.
- Detailing the issues associated with a perceived need to build expensive and unnecessary infrastructure requirements for CFTs.
- Addressing the inability to conduct locally relevant biosafety research and risk assessments.
- Raising issues related to lack of transparency or undue political influence and the corresponding impacts on the regulatory review process.
- The lack of monitoring, enforcement, or response capacity.
- Addressing the fact that there are too few well-trained regulatory specialists who can act independently.
- Communications training for decisionmakers so that they can effectively discuss the results of regulatory reviews and actions with nonspecialists.

The Role and Impact of the CPB: Regulatory Policy Concerns

The CPB was adopted on January 29, 2000, as a supplementary agreement to the Convention on Biological Diversity. It entered into force on September 11, 2003. To date, 160 individual countries are parties to the protocol. The EU as a regional bloc is allowed representation as a single party, although individual countries within the EU are also parties. There are 34 nonparties, including Argentina, Bahrain, Canada, Chile, Jamaica, the Russian Federation, San Marino, the United Arab Emirates, the United States, and Uruguay.

The CPB is primarily an international trade agreement on biodiversity formalizing biosafety assessments as a precondition for GE crop approvals for transboundary movements. Once the protocol became operational in 2003, it became a major driving force for the development of national regulatory systems; it has triggered the development of public- and private-sector research policies and R&D innovation management, particularly for countries that are parties to the protocol, as well as broader considerations regarding the regulation of genetically modified organisms (GMOs).

The stated objective of the protocol is to ensure "an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements" (Article 1, page 3).

The CPB is now being implemented. Its scope has been expanded beyond the impacts of biotechnology on biodiversity and the environment to include broad policy issues such as liability and redress, socioeconomic factors, public participation, labeling, and GMO detection. Parties are also expected to address their administrative responsibilities since ratification. A number of these are included in Box 3.

Many of these key issues have led to contentious policy discussions requiring multiple negotiating sessions in order to develop consensus or compromise. Two of the most currently discussed issues relate to (1) liability and redress and (2) the inclusion of socioeconomics in biosafety decisionmaking. Discussions of these two issues, in addition to the African Model Law on Safety in Biotechnology developed by the Organization for African Unity, are presented in more detail below.

BOX 3 Key issues included in the Cartagena Protocol on Biosafety (CPB)

- Assessment and review
- Capacity building
- Compliance
- Financial mechanisms
- Handling, transport, packaging, identification
- Information sharing
- Monitoring and reporting
- Risk assessment and risk management
- Public awareness and participation
- Liability and redress
- Socioeconomic considerations

Source: Compiled by the authors.

Liability and redress

Article 27 of the CPB requires parties to adopt and implement international rules and procedures for liability and redress in connection with damage that may result from transboundary movements of GMOs. The two primary types of liability that are being considered for biotechnology products are civil and administrative, although a third type exists.

Civil liability refers to a defendant's liability that forces compensation of a claimant (plaintiff) for damage caused to individual property, provided (1) that liability can be quantified in monetary terms, (2) that damage was reasonably foreseeable, and (3) that damage can be effectively linked to the individual claimant and the proposed offending party. Most civil cases are concerned with personal rights; therefore, this is an unlikely mechanism to protect broad public interests, such as protection from unknown environmental damage.

Administrative liability operates at the national level. An administrative system provides legal authority that requires preventive or remedial measures by developers or producers for environmental damage and provides judicial recourse for situations in which "offended" parties (persons or organizations) can direct claims against offenders and authorities that are accountable. An administrative approach may be useful to assign fault for possible future impacts that are not known today, whereas civil liability is limited to damage already known.

Strict liability is a standard of conduct required to attach liability to people or institutions that engage in inherently hazardous activities or, in the case of specific manufactured products, to any entity or person engaged in the production process (from the developer to the manufacturer to the wholesaler to the retailer) who could be held responsible if the product is deemed defective or harmful. Within the scope of strict liability, the person implementing the activity is responsible for the damages his or her actions or products cause, regardless of any "fault" on his or her part. Strict liability usually applies to harm resulting from abnormally dangerous conditions and activities or to harm that results from the miscarriage of an activity that, though lawful, is unusual, extraordinary, exceptional, or inappropriate in light of the place and manner in which the activity is conducted.

In October 2010, at the Fifth Conference of the Parties Meeting in Nagoya, Japan, a Supplementary Protocol on Liability and Redress (SP-NK) was adopted. Its objective is to "contribute to the conservation and sustainable use of biological diversity, taking also into account risks to human health, by providing international rules and procedures in the field of liability and redress to living modified organisms" (CBD 2011a, 2).

Although many of the existing international treaties that consider liability and redress emphasize civil liability rules for damage, the supplementary protocol pursues an administrative liability approach to addressing damage from GMOs. The SP-NK holds the identified authority ("competent authority") responsible for developer or operator actions undertaken in response to damage caused by GMOs.

In the SP-NK, *damage* is defined as an adverse effect on the conservation and sustainable use of biological diversity that is *measurable* and *significant*. It additionally defines parameters to determine the significance of the damage, instructs the parties to the protocol to take "response measures," and assigns responsibilities accordingly. The SP-NK does allow for the possibility of implementing civil liability in the future.

Going forward, steps that the parties will need to take with regard to this topic include the following:

1. Review existing laws and administrative arrangements to determine whether they will ratify the supplementary protocol and how they will implement it in practice.
2. Assess biodiversity baselines in order to assess damage that is defined as a "significant" adverse effect.
3. Determine damage causality between the use of a GMO and actual damage.
4. Identify the "operator" or "operators." This is a task assigned to the competent authority in-country, defined as the party's entity in charge (typically a body of a national government). The competent authority must further define the activity that caused damage and determine which operator(s) was in control of the GMO at the time of damage.
5. Define and implement response measures. The parties will require the operator(s) to take appropriate measures if damage occurs. The competent authority will need to determine the appropriate measures and whether additional measures are needed beyond those taken by the operator(s).
6. Provide financial security mechanisms including, but not limited to, insurance, insurance pools, self-insurance, bonds, state guarantees, fees, and other instruments.
7. Consider the use of civil liability procedures as a means of in-country recourse.

Possible response measures being considered might include actions to

- prevent, minimize, contain, mitigate, or otherwise avoid damage, as appropriate, and
- restore or replace biological diversity lost.

Possible capacity needs that have been identified to effectively implement the SP-NK are shown in Box 4.

BOX 4 Potential capacity building needed to implement the Supplementary Protocol on Liability and Redress

- Assess whether countries need to amend their laws, rules, or regulations to implement the protocol.
- Establish baseline data on biodiversity.
- Develop the skills necessary to evaluate adverse effects, determine their significance, and determine the causal link to a living modified organism or genetically modified organism.
- Enable competent authorities to determine response measures.
- Enable determination of a "sufficient likelihood of damage" and appropriate response measures.
- Determine whether parties wish to exercise their rights for providing financial security and how.
- Determine whether civil liability rules and procedures are needed to implement Article 12.
- Determine whether states desire to bring claims with alternative liability and redress mechanisms.

Source: Extracted from Garforth (2011).

Socioeconomic considerations

Article 26.1 of the CPB raised the option of including socioeconomic considerations as part of the decision-making process. The implementation of this article is voluntary and has a scope limited to those factors affecting biodiversity and its value to indigenous and local communities.

The CPB does not mandate the inclusion of socioeconomic considerations, although countries have the sovereign right to include it. Introduction of broader socioeconomic considerations into GMO biosafety analysis and the decisionmaking process is controversial because there are many approaches and options for regulatory design, development, and implementation. These, in turn, have implications for costs, benefits, risks, and trade-offs related to technology use, safety, gains in knowledge, and regulatory impact. Countries must decide, at the outset, whether this parameter should be included in a regulatory decisionmaking framework. Arguments in favor of inclusion relate to a more holistic decisionmaking process (reliant on factors beyond science) that could favor the use of biotechnology by developing information in the regulatory process that addresses adoption benefits and constraints. Arguments against inclusion relate to additional costs that may place an undue burden on public-sector research, regulatory uncertainty and inefficiency, and ill-defined parameters (Horna, Zambrano, and Falck-Zepeda 2013).

An example of how this has been applied is the case of insect-resistant potatoes in South Africa. In this situation, the product was judged to be scientifically safe for food, feed, and the environment but was rejected by the regulatory process due to potential negative impacts on trade and social impacts on small-scale farmers (Thomson, Shepherd, and Mignouna 2010).

Going forward, countries will need extensive support to help them make decisions about the inclusion of socioeconomics in regulatory frameworks and to develop the guidelines that will be required as a result. Horna, Zambrano, and Falck-Zepeda (2013) illustrate a specific methodology to use when including socioeconomic considerations in biosafety decisionmaking.

Countries will need to define the scope of socioeconomic considerations in their decisionmaking. Most countries in Africa are signatories to the CPB but are also signatories to the World Trade Organization (WTO). The WTO has specific provisions for socioeconomic considerations related to those issues affecting trade, and thus there may be some limitations in terms of what countries can do regarding socioeconomic considerations in biosafety or technology decisionmaking. A more extensive discussion of this issue can be found in Jaffe (2005); Falck-Zepeda (2009); Falck-Zepeda and Zambrano (2011); and Horna, Zambrano, and Falck-Zepeda (2013).

The African Model Law on Safety in Biotechnology

The African Model Law on Safety in Biotechnology, now the African Union (AU) Model Law on Safety in Biotechnology (African Union 2001), has been guiding biosafety regulatory policy in Africa since it was first developed in an Organization for African Unity (OAU) workshop of experts held in Addis Ababa in June 1999. The first draft of the African Model Law was based on a proposal submitted to the Convention on Biological Diversity (CBD) Secretariat during the Third Conference of the Parties of the Biosafety Protocol, held in Buenos Aires in 1996 by the African Group. The first draft was finalized in Addis Ababa in May 2001 by an OAU working group, which brought together 50 representatives of 28 African governments; 34 representatives of nongovernmental organizations (NGOs), scientific institutions, and the biotechnology industry; and 5 representatives of the OAU and UNEP-GEF. It was presented at a meeting of the AU Executive Council held in Maputo, Mozambique, in July 2003 by the AU Commission. The AU Executive Council, in its Decision EX/CL/Dec.26 (III) m, urged AU member states to use the African Model Law as *a basis for drafting their national legal instruments on biosafety.* This advice has been followed by a number of countries throughout Africa in the development of their national biosafety frameworks and biosafety regulations.

Many have criticized the African Model Law as too restrictive, with a primary focus on the risks versus the benefits of agbiotech. Somewhat paradoxically, the AU has expressed a need to achieve a balanced approach to the assessment and use of the African Model Law by its member countries. Its website proclaims, "It is clear that African countries will generate modern biotechnology products and processes and will not be mere recipients. Therefore, the Model Law should not restrict investment in biotechnology, rather it is aimed that it acts as a facilitative instrument driven and informed by science to assist countries to maximize the benefits of biotechnology, while avoiding or minimizing the risks" (www.africa-union.org/root/au/auc/departments/hrst/biosafety/AU_Biosafety_2b.htm).

The 2001 draft of the African Model Law has been subsequently revised at national and regional meetings in Africa. The Revised Model Law was introduced at the Africa-wide Experts Meeting in Lusaka, Zambia, in 2007. A final revision was presented at the 12th session of the African Ministerial Conference on Environment in June 2008. The ministers endorsed the process and further called for the AU Commission to provide biosafety leadership to ensure the harmonization of country-level positions into a common African position. This draft Revised Model Law is still being adjusted based on inputs from regional discussions. It is expected that the Revised Model Law will eventually be presented to the ministers of trade and industry and the ministers of agriculture for extensive participation in the process. As described by Mayet (2003), the African Model Law currently establishes the following:

- Uniform provisions for the import, export, transit, contained use, release, and placing on the market of any GMO or a product of a GMO, whether it is intended for release into the environment, for use as a pharmaceutical, or for use as food or feed for processing.
- Stringent regulation of GMOs in which decisionmaking is based on the precautionary principle.
- Strict regulation of GMOs imported for use as food or feed for processing and as food aid.
- Public participation.
- Identification, traceability, and labeling systems.
- Liability and redress approaches.

Although the passage of the African Model Law has raised the profile of biosafety as an issue for GM crop introduction in Africa, it is clear from the above description that certain aspects of the law may actually limit progress for countries wishing to use GM technologies. A case-by-case or event-by-event approach is not necessarily consistent with technical best practices in many adopting countries. Calls for regionally binding decisionmaking are at odds with some harmonization efforts (such as those of COMESA) and some national regulatory positions. Strict liability is also a problem, because many African countries have not adopted this approach in their national regimes (for example, Kenya, Nigeria, and South Africa). There are also dissimilar opinions about the utility of the African Model Law that have led to diverging regulatory schemes in Africa and a lack of consistency as to how regulatory principles are being applied. These could cause serious issues for trade and commerce for a continent with porous borders and weak enforcement mechanisms.

Continuing efforts to obtain resolution on the content, scope, and impacts of the African Model Law should be prioritized and supported with adequate technical and financial resources.

Regional Harmonization Efforts in Biosafety

Pursuit of harmonized regional biosafety policies is listed as a key recommendation (no. 18) in the report of the AU/NEPAD High-Level Policy Panel on Biotechnology (Juma and Serageldin 2007). Most experts agree that harmonization efforts will contribute to greater regulatory efficiency in biotechnology decisionmaking overall but will likely not substitute for the development of strong national systems. Rather, they are intended as a means to promote trade and commerce and to minimize any potential negative effects that might result from cross-border flows of GM products and technologies.

Over the past seven to eight years, Africans have expended significant efforts in attempts to establish regional biosafety policies, guidelines, or regulations. These efforts have been designed to provide uniform rules and procedures that would allow for regional trade in GMOs and to simplify the approval processes for GMOs by eliminating the need for every African country to establish de novo national biosafety regulatory systems. To date, these efforts have not resulted in any approved or adopted regionally binding document. They have, however, raised the profile of biosafety issues at both the regional and national levels throughout the continent and have contributed to biosafety capacity building.

The following is a summary of four of the major African regional biosafety initiatives and their current status. Those working on each initiative have spent considerable effort on regional harmonization and have proposed guidelines, policies, or regulations that may be beneficial to the countries involved. No initiative has progressed to a completed product, and it is unclear whether any will be finalized in the foreseeable future. Even without a consensus document that is implementable, provisions established in the harmonization process may still be models that are adopted by individual countries in national regulatory frameworks.

The Common Market for Eastern and Southern Africa (COMESA)

Beginning in 2003, the COMESA ministers of agriculture endorsed the Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa (RABESA) project with a goal of establishing mechanisms for managing biosafety issues at the regional level.

The key partner institutions supporting COMESA in the implementation of RABESA have been the Association for Strengthening Agricultural Research for Eastern and Central Africa (ASARECA), PBS, and ISAAA. In 2009 the Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA) was created as a specialized agency of COMESA. In 2010 the implementation of RABESA moved to the Biotechnology and Biosafety Program of ACTESA.

Early on, a series of regional consultative meetings were held to identify the scope of the initiative. RABESA identified three areas for a regional harmonized approach involving biosafety: (1) the commercial planting of GM crops, (2) trade in GM products, and (3) the provision of emergency food aid with GM content. Regional experts and country representatives met to draft policies and guidelines for each of those three areas. The commercial planting guideline establishes a regional committee to carry out a regional risk assessment of GMOs that are to be planted in the region that can then be used by individual national biosafety regulators to make approval decisions. The policy on trade in GM products identifies how different GM products should be treated by COMESA countries depending on whether they originated from a country within or outside the COMESA group of nations. Finally, the emergency food aid portion of the guidelines articulates procedures that are to be used by COMESA countries to review and approve emergency food aid that may contain GM content coming from both COMESA and non-COMESA countries.

At COMESA's ministerial meeting held in Sudan in 2007, the ministers endorsed the drafting of regional biosafety policies and guidelines around the three areas of focus identified by stakeholders. The ministers also recommended the formation of a Panel of Biotechnology and Biosafety Experts to serve as a technical advisory body of COMESA; this took effect in December 2008. The drafting of regional biosafety policies and guidelines started in 2008. The documents were subjected to several rounds of technical review. A regional workshop of COMESA member states was held in Nairobi in April 2010 to discuss and review the document.

Ministers at COMESA's Third Joint Meeting of the Ministers of Agriculture, Environment, and Natural Resources, held in July 2010 in Zambia, resolved that national consultative workshops on the three draft regional biosafety policies and guidelines should be conducted in all COMESA member states. The RABESA team presented the draft biosafety guidelines to most COMESA member states in consultative meetings for their comments and endorsement in 2010 and 2011. By July 2011, 14 workshops had been held in Burundi, the Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Malawi, Rwanda, Seychelles, Sudan, Swaziland, Uganda, Zambia, and Zimbabwe. COMESA's Fourth Joint Meeting of the Ministers of Agriculture, Environment, and Natural Resources was held in July 2011 in Swaziland. The ministers attending resolved that national consultations should be completed in the remaining COMESA countries (Comoros, Djibouti, Libya, Madagascar, and Mauritius). Regional workshops of COMESA member states were organized to review the consolidated document, address any proposed changes, and prepare a final document for presentation and adoption at COMESA's Fifth Joint Meeting of the Ministers of Agriculture, Environment, and Natural Resources. During this meeting, held in September 2013 in Addis Ababa, the ministers of member states endorsed the policy recommendations of the technical committee on biotechnology and biosafety. Following the final approval of the COMESA Council of Ministers in February 2014 in Kinshasa, each COMESA member state has been able to simplify its regulatory decisions. This allows for a clearer and more consistent path for regulatory approval of GMOs in member states through a regionalized risk-assessment auditing process. The regional policy also provides for sharing of capacities and for uniform treatment in regional trade involving both seed and grain GMOs, including emergency food aid.

The Economic Community of West African States (ECOWAS)

The ECOWAS regional biosafety initiative began in 2004 as a project led by the Institut du Sahel (INSAH) to develop a regional convention that established a common biosafety regulatory system in the countries of the Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) as well as a regional coordination framework. The draft documents that were developed set forth a regional regulatory system whereby (1) each country establishes its own national biosafety regulatory system using the procedures, definitions, and responsibilities for their national competent authority set out in the CPB process; (2) the national authorities make most of the decisions regarding the authorization of activities using GMOs; (3) the INSAH/CILSS Regional Consultative Committee (RCC) reviews and advises on proposed national decisions on particular GMOs and provides general technical and policy support to the national competent authorities; and (4) the RCC makes some authorization decisions for countries without regulatory frameworks in place or when products will be marketed throughout the region. Thus in most situations the proposed regional system was a decentralized and nonbinding one that placed legal authority for authorizations with each member country but provided harmonization, technical support, and regional oversight of the procedures used to make authorization decisions through the RCC.

Before the CILSS countries could finalize their regional convention and begin the adoption process, it was decided that ECOWAS would take over the process and use the existing documents as a starting point for a broader regional initiative that would cover all of its countries. A June 2005 ECOWAS Ministerial Meeting held in Bamako, Mali, resulted in an ECOWAS action plan for biotechnology for 2007–2012 (to be implemented in collaboration with CORAF and INSAH/CILSS), which included the recommendation of a regional approach to biosafety. Key objectives of the regional approach were (1) to create a regional biosafety regulatory framework (harmonization of rules and procedures), (2) to have national biosafety frameworks developed and adopted in harmony with the regional biosafety framework, (3) to promote an understanding of the Convention on Biological Diversity and the CPB, (4) to strengthen the capacity of national stakeholders for the implementation of the regulation, and (5) to strengthen laboratory capacities in diagnosis.

Over the past two years, ECOWAS has taken over the process, resulting in a regional biosafety regulation discussed below in the section on WAEMU. It should be noted, however, that the regional regulation currently being reviewed by ECOWAS countries under that joint initiative is significantly different from the documents developed by CILSS. If that process does not result in a single harmonized regulation in the region, it might be beneficial for the ECOWAS countries to take a second look at the CILSS biosafety documents, because they did set forth valuable procedures and guidelines that would allow for more uniform and science-based biosafety regulatory systems in the region.

The West African Economic and Monetary Union (WAEMU)

In 2008 the World Bank and WAEMU agreed to establish a regional biosafety project. That project included as one of its three main components the establishment of a regional biosafety regulation for the WAEMU member states. When the project was started in 2009, however, it was agreed that WAEMU would work with ECOWAS to draft a regional biosafety regulatory framework that could be adopted by all West African countries, not just the member states of WAEMU. Thus ECOWAS and WAEMU drafted a joint regional biosafety framework and conducted numerous consultative meetings on the draft in their member countries.

A 2012 draft of the ECOWAS/WAEMU regional biosafety framework was made public during the country consultation stage. The draft is significantly different from the document developed earlier with CILSS. It sets forth a fairly strong centralized body to make decisions on the approval of commercial GMO products and allows for mutual recognition of GMOs so that trade among countries involving GMO products will be easier. However, the draft document also covers several topics that are highly controversial internationally, including the incorporation of socioeconomic and ethical considerations into approvals and decisionmaking and the establishment of stringent liability and redress standards if a GMO causes harm. Given the feedback that the regional bodies received from member states and interested international stakeholders, it is unclear whether this document will move forward and what changes, if any, will be made in that process.

The Southern African Development Community (SADC)

A 2003 Council of Ministers directive of the SADC established an Advisory Committee on Biotechnology and Biosafety of the 15 representative countries. The focus of the committee was to consider a regional harmonization effort focused on policies related to the handling of food aid, biosafety policies and regulations, capacity building, and public awareness (Karembu, Nguthi, and Ismail 2009). The recommendations developed for biosafety were highly precautionary, included language derived from the African Model Law, and formulated guidelines to "safeguard Member States against potential risks in the areas of human and animal food safety, contamination of genetic resources taking into account ethical and trade-related issues including consumer concerns" (Zarrilli 2005, 22). The effort has faltered in recent years, plagued by the widely polarized viewpoints of member states and an inability to achieve consensus.

INTELLECTUAL PROPERTY RIGHTS (IPR) AND RELATED ISSUES

Intellectual Property and Biotechnology Development Issues

GM crops have the potential to increase food security and reduce poverty in the developing world. However, most of the technologies for GM crops have been developed by the private sector and are likely to be proprietary. This is an important difference between these new GM varieties and those that were developed during the Green Revolution, primarily with public funding. The proprietary nature of GM crops poses a number of issues regarding access to these technologies and the associated products or varieties, as well as their use and transfer.

Most of the IPR for agricultural biotechnology are protected by some combination of licensing and commercialization arrangements among various and multiple owners, especially in the United States and other industrialized countries. At the present time, IP for agricultural biotechnology is held by private companies in Canada, Europe, Japan, and the United States. The "weak" IP systems characteristic of most developing countries has been a disincentive to the private sector with respect to the deployment of proprietary technology. The problems are not specific to the private sector. In the developing world, the public sector has a slightly higher percentage of ownership. Public-sector portfolios include both enabling technologies representing the research tools needed to create GM crops and the "trait" technologies that provide the genetic basis for new functionalities (Graff et al. 2003). Public-sector agbiotech inventors and developers in countries with weak IP systems also need to maneuver within a complex environment of IPR laws at the domestic, regional, and international levels. The situation becomes increasingly problematic for public-private initiatives wishing to develop situation-specific GM crops (Kerle 2007) of use to Africa and other developing world regions because the partners may have differing agendas and differing standards of IP protection.

The effect of this complex proprietary environment increases already high transaction costs for obtaining the necessary permissions from all IP owners to enable the R&D of a product or technology. To protect an invention, applications filed and patents granted may need to be filed in at least four offices: the US Patent and Trademark Office (USPTO), the European Patent Office (EPO), the Japanese Patent Office (JPO), and the office of the international Patent Cooperation Treaty (PCT) for agricultural plant biotechnologies, further increasing the paperwork and costs. Patent and other IP protection instruments must be filed and maintained in each country where the developer wants to pursue a market and protect the invention. Moreover, the applicant must be willing to defend its patent in the event of jurisdictional breach or noncompliance.

There is a great degree of discrepancy about the potential role of IP systems and their relative impacts on the economies of developed and developing countries. An important part of the literature on this topic proposes a direct link between the existence of strong IP protection and R&D investments, innovation, and a nation's economic growth. Opposing views contend that strong IP protection may have undesirable consequences related to reductions of biodiversity, negative impacts on farmer-based seed systems, and, consequently, adverse effects on food security for the world's poor.

Many of these discrepancies may be explained by a lack of understanding about what constitutes a "strong" IP system; in some cases this has been narrowly interpreted as a patent system and the ability to patent. The problem with this quite narrow interpretation is that it does not consider the variety of IP protection instruments available and the many trade-offs involved in terms of policy, laws, regulations, and impacts.

An alternative view is that, despite this complex situation with IPR, in actual operation they are not a constraint for countries that lack patent protection because property rights are confined to a geographical jurisdiction. This situation is applicable to those countries that invest in and produce GM crops that are sold only in local markets (Pardey et al. 2003). However, there is a potential for negative results in countries that take this approach. This "freedom to operate" can be challenged because countries that produce in the near term only for domestic markets may potentially compromise their future export opportunities and ability to compete in a global agriculture environment. This may be especially important for the countries of Africa, which are looking at ways not only to increase their domestic agriculture production but also to enhance their positions as global agriculture competitors. African countries need to carefully weigh the short-term exploitation of technology not protected in local markets against longer-term scenarios, especially against the impacts on indigenous innovation systems. In essence, countries should examine all of the potential consequences related to the development of national IP policies, taking into account short-term gain versus longer-term needs and opportunities.

Laws and regulations governing IP also need to look at the potential trade-off between the rights and obligations granted to the individual and the benefits, costs, and risks of the technology to society. This becomes a major issue for most developing countries struggling to design their systems to protect multiple interests, including those of their own farmers and those of inventors, regardless of their source. In fact, in some situations African countries as well as other developing countries might consider the adoption of an IP system that exploits the total flexibility afforded to them by international agreements. However, the bottom line is that this discussion has not taken place from a comprehensive perspective at senior levels of most African governments. Instead, the ongoing discussion with respect to biotechnology and patents has been very myopic; it usually disintegrates into a very narrowly based discussion of rights and social justice and does not deal expansively or adequately with all of the issues from a socioeconomic and trade perspective at the individual-country or regional level. It is a point to consider going forward because it has been a contentious issue.

IPR, trade, the Trade-Related Intellectual Property Rights (TRIPs) agreement, and Africa: What are the issues?

As indicated above, the issue of IPR protection, pro-poor access, and biotechnology has been a subject of heated debate in the developing world, including Africa. Accession to the WTO requires compliance with its TRIPs agreement. Because most countries in Africa are signatories of the WTO, they are required, eventually, to comply with the TRIPs agreement.

The TRIPs agreement mandates that its members establish a system of plant variety protection. This could include plant patents, an effective sui generis system, or any combination of the two. The TRIPs agreement does not force countries to use patents; rather, it mandates that they have some protection system in place. Article 27.3 (b) of the TRIPs agreement provides the main requirements for IP protection for GMOs. This agreement has become the epicenter of the debate about GMOs, innovation, and social rights (Graff et al. 2003).

The vast majority of developing countries have weak or nonexistent IPR systems for inventions relating to GMOs, including plants and animals (Kerle 2007; Pray and Naseem 2007). Many developing countries, although only a few in Africa, have become members of the International Union for the Protection of New Varieties (UPOV) as a way to fulfill their TRIPs obligations. As of December 2013, only four African countries (Kenya, Morocco, South Africa, and Tunisia) were members of UPOV.

Clearly, the issue of IPR protection and agriculture has been problematic for many African countries, which are struggling with the need to reconcile traditional agriculture practices with the TRIPs requirements. Most lack protection of any form. Among African countries that are members of the WTO, all but 14 are defined as "least-developed countries" (LDCs) and, as such, were initially granted an extension for TRIPs compliance until 2013. Now this extension has been moved to 2021.

The situation in Africa is further complicated because there are two major regional treaties, which created the African Intellectual Property Organization (OAPI) and the African Regional Industrial Property Organization (ARIPO). Each has its own set of operational procedures and implications for IP protection. Furthermore, the AU has been used by some countries to develop sui generis systems that also have a defined set of provisions.[6] Box 5 contains an overview of IP obligations.

The problem of not having an adequate IPR system in place is that it gives little incentive to advanced technology developers to engage. For agbiotech in particular, countries with weak IPR systems are likely to face a difficult time trying to access protected GM technologies, the bulk of which are aggressively protected under a variety of IPR regimes in key and ever-expanding international markets. Biosafety approval systems, which often require documentation containing proprietary or confidential information, pose additional challenges. The lack of effective IPR protection for agricultural innovations in many countries of Africa, along with the potential adverse effects on technology access and R&D, is a serious hurdle for the future development of an indigenous agbiotech sector.

The other point under debate is whether there is a need to harmonize IPR systems in Africa. Whether potential harmonization across countries in Africa will result in benefits that outweigh the costs is a question debated in policy circles and at regional forums. However, the literature suggests that harmonized standards for the IP protection of GMOs will benefit all concerned countries.

Unlike pharmaceuticals, agbiotech products (especially new varieties) are not generally transferable from developed-country settings to those in developing countries. Products suitable for Africa need to be developed domestically using local germplasm to ensure adaptation to the local conditions. Therefore, both the developed country owning a gene and the African partner owning a variety and contributing local knowledge stand to gain from the interaction. Harmonization of IP regimes across Africa will lead to improved implementation of

6 A sui generis system of protection is defined as "a special form of protection, a form that is particularly adapted to a specific subject or to specific circumstances, that is especially tailored to specific needs, priorities and reality" (FAO 2000, section 7.3.1).

BOX 5 The African regional intellectual property (IP) treaties

The African Intellectual Property Organization (OAPI)

Formed under the 1999 revision of the Bangui agreement (including Benin, Burkina Faso, Cameroon, the Central African Republic, Chad, Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, and Togo), OAPI agreed to a set of provisions to accommodate compliance with the Trade-Related Intellectual Property Rights (TRIPs) agreement. These provisions included mandatory accession to the Union for the Protection of New Varieties (UPOV) 1991. The OAPI is a single regional body acting as the national patent rights authority on members' behalf. This implies a type of uniformity with respect to legislation and application procedures and a single window to or single granting authority for patent protection. According to Thorpe (n.d.), "Patents granted by OAPI are considered to be independent national rights subject to the legislation of each member state. All members of OAPI are automatically designated."

The African Regional Industrial Property Organization (ARIPO)

ARIPO was established under the 1976 Lusaka agreement and was later revised in 1985. Countries under the Lusaka agreement (including Botswana, Gambia, Ghana, Kenya, Lesotho, Malawi, Mozambique, Sierra Leone, Somalia, Sudan, Swaziland, Uganda, the United Republic of Tanzania, Zambia, and Zimbabwe) later signed the Harare Protocol (except for Somalia), which empowers the countries to receive and process patents at the regional level but to retain their national sovereignty as individual countries to grant patents. In other words, ARIPO countries have maintained their national IP systems.

The African Model Law on Safety in Biotechnology developed by the Organization for African Unity

Although not a regional agreement, the African Model Law has provisions for protecting the rights of local communities, farmers, and breeders and for the regulation of access to biological resources, and it includes a recommendation that the patenting of life forms should not be allowed.

Source: Compiled by the authors.

Note: In this box, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

acceptable IPR systems for innovators and could have positive impacts, both locally and regionally, on the diverse partners currently involved in technology transfer arrangements (such as the research initiatives between NARSs and multinationals on nitrogen-efficient rice or drought-tolerant maize). Better IP standards can also encourage foreign direct investments. Private foreign investors wishing to undertake research that could benefit developing countries are likely to invest in those countries that have effective IP regimes. Attraction of private capital will, in turn, encourage technology transfer (Kerle 2007), so the situations of IP, technology, and capital may be somewhat interlinked.

An evolving situation for IPR protection and plants

The use of instruments to protect IP rights related to plants, animals, and other living organisms has indeed been controversial. There is tension between the recognized need to reward plant breeders for their inventions and the concerns about monopolistic effects, however temporary, on the food supply as a result.

UPOV 1991 requires the adoption of a system that gives the plant breeders IP protection while prohibiting others from the multiplication, propagation, sale, and export, import, and stocking of materials for commercial purposes. It extends plant breeder rights to harvested materials by prohibiting the same activities in relation to propagation. Rights granted to inventors do not restrict the use of plant varieties for research purposes, known as the "breeders' exemption," but do restrict seed saving by farmers. Farmers are allowed, for some crops, to save seed, but only for use as personal holdings. This is a critical point that is frequently raised regarding biotech crops but in fact applies to any legally registered variety under UPOV protection, regardless of the method by which the variety was produced.

In spite of the fact that some African countries are adopting either UPOV or TRIPs agreements, controversy continues on the proper role of IP protection systems to promote innovation and growth. A key issue is related to the impact of national IP policy decisions on trade in GM crops; the export potential of IP-protected crops definitely affects a given country's IP laws (Binenbaum et al. 2003; Pray and Naseem 2007). In Africa the most important IP-protected GM products (with the exception of soybeans, bananas, rice, and topical crops) are largely traded between African countries with equally weak systems; thus patent infringement may not be a serious issue as long as the products are commercialized and used in that geographical context (Binenbaum et al. 2003). In this scenario, the lack of scientific capacity and the absence of functional regulatory frameworks may be a more significant impediment to biotech innovation than the quality of an IP system (Binenbaum et al. 2003; Pray and Naseem 2007). However, it does become an issue when protected technologies are exported in commercial trade (by other than the inventor) to markets where the invention is protected. This could raise noncompliance issues for the exporting country with the owner of the proprietary technology.

In recent months there has been increased interest in the impact of the expiration of patents for a number of major biotech traits and enabling technologies, especially in developing countries. PBS is in the process of completing a research project that will detail the challenges of and opportunities for developing countries in this evolving scenario. Preliminary conclusions suggest that, for many of the reasons noted above, a postpatent regime would not necessarily affect a country's decision to use a generic biotech invention. In a survey of experts done by PBS, none of the experts expected that generic transgenic crops would be developed and used in Africa. An alternative scenario, which could involve the production of generic biotech traits by skilled emerging economies (such as Brazil or China), which are increasingly engaged in Africa, may affect the situation more directly. If such generics were able to address market capacity constraints and regulatory requirements to advance to commercialization, they could foster competition with proprietary branded technologies; this could result in reduced seed prices or increased availability for resource-poor farmers. At issue would be concerns related to regulatory responsibility for generics—who would be responsible for submission of and updates on regulatory data, for example? The six major companies involved are in the process of setting up a regulatory data exchange mechanism that could allow them and others to access data in exchange for compliance with certain stewardship and liability rules.

Experiences with public-sector technologies and private-sector humanitarian donations of technology (such as Golden Rice) have shown that IP issues can be effectively negotiated and managed. However, developing-country partners generally lack this skill set, and this is an area that needs further capacity building in Africa in particular. In 2003 SIDA instituted a capacity-building program called GRIP (Genetic Resources and Intellectual Property Rights) in recognition of the fact that many developing-country scientists and policymakers lack the required skill set to effectively deal with technology access and management. The program is not Africa-specific, however. AATF, located in Nairobi, was founded to act as an honest broker in complex PPP negotiations on behalf of the African technology-sharing partners. This is a good model but does not substitute for a locally based skill set in technology transfer practices, especially for countries that are placing a high priority on biotechnology. Education on IP and national innovation, in the form of workshops and other types of training, is needed in public-sector institutions. Well-trained policymakers, lawyers, and technology transfer professionals can provide the necessary capacity for an effective IP framework. Countries also should explore alternative public policies and other IP protection instruments, such as humanitarian licenses, patent pools, government purchases of licenses, vouchers for supporting research competitions, and so on.

Access and Benefit Sharing

Developing countries have been a source of genetic resources that have been used by the developed world in the creation of new varieties that are then protected as proprietary products. This has been a source of frustration and concern for many developing countries, especially those that have a rich platform of genetic resources. It has given rise to debates about equity and social justice around the patent system. Access and benefit sharing (ABS) refers to compensation schemes for the equitable sharing of benefits between the country of origin of a specific genetic resource and the individuals who subsequently commercialize the plant variety or other product. ABS was not a concept contained in the original Convention on Biological Diversity (CBD) document (CBD Secretariat 2000). Yet the concept has been incorporated into the Nagoya Protocol on Access to Genetic Resources and Equitable Sharing of Benefits Arising from their Utilization, adopted in 2010. The Protocol was up for signature by CBD parties until February 2014 and by April 2014 had been signed by representatives of 92 countries (CBD Secretariat 2011b). Of these countries, 32 had ratified it.

The diversity of legal and regulatory frameworks, stakeholder interests, the inability to identify competent authorities to implement ABS schemes, identification of activities covered in the scheme, payment mechanisms, identification of owners, disbursement of funds, and other issues have proved to be difficult barriers to overcome.

Benefit sharing itself may be subject to divergent or even contradictory interpretations. In some cases a benefit may be strictly interpreted as monetary, whereas in other cases it may imply license-free access to the technology developed using the genetic resource or possibly access to research capacity or to human resources for scientific innovation. It may also be as simple as an acknowledgement of origin or a complete characterization of the genetic resource. The defining characteristic is that clear standards of management need to be established early on to avoid uncertainty and ownership disputes in the R&D, regulatory, IPR, and commercialization processes.

Within the discussion of benefit sharing, the protection of "traditional knowledge" (TK) has emerged as a driving concept. TK is often associated with plants, animals, fish, and other organisms and with the community identification of special characteristics that may be of value to the community at large. Because TK is often associated with local customs and laws, some claim that there is a need to develop or modify IP protection schemes that recognize and reward the contributions of TK in the invention process. What has become clear is that ownership of genetic resources, patent rights, TK, and benefit sharing present a complex array of issues that are confounding the debate about agricultural biotechnology and the developing world.

Terminator Technology and Farmers' Rights

Genetic use restriction technologies (GURTs)—commonly referred to as terminator technologies by some antibiotech groups antagonistic to most genetic engineering—describes a set of genetic methodologies that restricts reproduction of an organism (for example, sterile seed) or renders a trait inactive in subsequent plantings. They were originally identified as a potential form of biological IP protection to compensate for weak IP laws in developing countries. GURTs are different from conventional hybrids that lose performance (hybrid vigor) after successive plantings, because the seed can be replanted but performance gradually suffers. The development of this technology created a firestorm of opposition and a huge public relations dilemma for the biotechnology industry.

Paradoxically, the use of GURTs can be advantageous to control gene flow and thus facilitate the process of coexistence between GM and organic and conventional production systems, especially when they operate in close proximity to each other. Disadvantages relate to the need to purchase seed every planting season and the perception that it could create farmer dependence on a multinational company that could potentially exert control over seed sales. The debate is fraught with emotion and resulted in one company's pledge to abandon pursuit of this technology. Nevertheless, the controversy lingers, affects perceptions about the "science" involved, and is raised as an issue, especially in the developing world, where seed saving is a common practice. More information can be found on Monsanto's website (www.monsanto.com/monsanto_today/for_the_record/monsanto_terminator_seeds.asp).

TRADE AND MARKETS

A Regulated International Market

Fifteen years after their introduction, and despite well-publicized opposition in certain Western countries, the four main GM products (maize, soybeans, cotton, and canola) are widely traded and consumed internationally, especially because the largest exporters of these crops are also the largest GM adopters. For instance, it was estimated that over 80 percent of maize and 94 percent of soybeans internationally traded in the world in 2005 were likely GM products (Gruère 2011b). The international market for GM products can be characterized by (1) a high concentration of trade in GM primary products in the four crops and limited shares in the few other GM products (for example, papayas and sugar beets); (2) general commingling, with GM grains mixed together with conventional non-GM grains in commodity trade; (3) the presence of specific import authorization procedures (for safety) and marketing regulations for GM food and feed in an increasing number of countries; and (4) a differentiated demand for pure non-GM products in these same countries, especially food products, but not as much for feed or nonfood products.

Given different national regulatory procedures and heterogeneous demand, the market is divided into large volumes of mostly GM commodity products for animal feed or nonfood items (cotton) flowing from GM-adopting countries to a wide range of other countries (including most African countries) and much smaller volumes of non-GM counterparts flowing from GM-adopting countries and others to countries with specific regulations and a demand for non-GM products.[7] This latter demand comes primarily from consumers in Europe, East Asia, and a few other countries, which perceive GM foods as unsafe, environmentally damaging, or ethically unacceptable and have translated

7 Unlike other products, transgenic cotton is mixed with conventional cotton and not regulated in international trade (ICAC 2010).

these perceptions into GM-free policies set up by large food retailers and manufacturers (see Gruère and Sengupta 2009a).

Beyond these formal trade flows, which represent almost all the trade volume of the products concerned (Gruère 2006a), GM seeds and products have also been moving informally across borders. Intentional introduction of unapproved GM seeds has moved across borders in multiple countries in the past, as demonstrated by the initial introduction of GM cotton in India and GM soybeans in Brazil. There is some indication that the same situation may be occurring in Africa; anecdotal reports indicate that GM maize has informally crossed borders in southern Africa (Gruère and Sengupta 2010) and may be imported formally and informally into Kenya (Kimani and Gruère 2010). These movements are generally driven by the will of farmers who want to use new technologies available in other countries. At the same time, unintentional commingling of unapproved GM products has, on some occasions, created important international market disruptions (Carter and Gruère 2012). The most memorable cases are those of GM rice and StarLink corn from the United States, which entered the global commodity market without approval, creating market bans on their respective commodities and lowering prices, with economic damage to US growers.

In this complex context, given that not all countries and consumers have accepted GM crops and that there are market niches and formal and informal trade, the issue of importing GM products is at the forefront of considerations for African countries setting up their biosafety and biotech regulations. In particular, several southern African countries have set up import bans of GM products, and many others have restricted their import of GM products from their South African neighbor (Gruère and Sengupta 2010). Some of these decisions were made in periods of food shortages, creating challenges for those making food security decisions, as we discuss later in this section.

A number of studies have analyzed the economic effects of using GM crops at the international level. A review of the international agricultural trade economics literature drew the following three transversal lessons from past studies (Gruère, Bouët, and Mevel 2011):

1. *"In the absence of GM-specific trade regulations, adopting a GM crop is generally beneficial and non-adopting importers will gain, while non-adopting competitors may lose"* (p. 288). This is especially visible in the case of cotton, whose international market is not affected by any regulation (Elbehri and MacDonald 2004; Anderson and Valenzuela 2007; Bouët and Gruère 2011). Adopters (Burkina Faso, China, India) gain if they adopt GM cotton, whereas their competitors (other western and eastern African countries) tend to lose.
2. *"Accounting only for their market effects, the introduction of GM-specific trade regulations reduces welfare gains, especially for non-adopters"* (289). Thus, if an African country decides to impose strict control on GM, it will likely bear negative economic effects (not accounting for perceived safety). The moratorium imposed by Benin and the trade restrictions set up by Zambia and Zimbabwe are bound to result in decreased consumer welfare by limiting access to grains produced in GM-adopting countries like South Africa, with price consequences.
3. *"Importers' regulations can reduce gains for exporting adopters"* (289). This can be seen again in the case of South Africa, which has largely adopted GM maize but was recently (in 2010) sitting on a surplus of maize that it could not sell to countries in the region because of their restrictive GM policies. Traders had to find buyers in Asia.

Put together, these three conclusions indicate that GM crops will tend to be beneficial to adopters and that there are significant costs associated with the imposition of specific GM import regulations on importers and exporters that adopt GM. This last point remains perhaps the most discussed in the African setting. Many African policymakers have raised concerns over potential export risks with the consumption of, experimentation on, or planting of new GM crops. Although export risks can be legitimate concerns, it is certainly not always the case, and coexistence does work in general. In fact, many of the largest countries producing GM crops are also heavily involved in non-GM or organic production, as shown in Table 13.

Managing Export Risks and Regulating Imports

How can we quantify the risk of losing exports when a country adopts a GM crop? A few simple studies have shown that the risks for most African countries are extremely limited, including those of Binenbaum et al. (2003) and Paarlberg (2006). Many other studies have included simulations to show the minimal if not negligible export risks faced by countries of Africa south of the Sahara (SSA) if they adopt the major GM crops (for

TABLE 13 Examples of countries producing both genetically modified (GM) and non-GM crops, 2012

TYPE OF CROP	CORN	SOYBEANS	COTTON	CANOLA
GM and pure non-GM	South Africa	Brazil, Canada, United States		Australia
GM and organic			Australia, Brazil, Burkina Faso, China, India, Pakistan, South Africa, United States	
GM, pure non-GM, and organic	Canada, Spain, United States			Canada, United States

Source: Carter and Gruère (2012).

example, see Anderson and Jackson 2005). In fact, several African decisions about the use of GM crops seem to have been made with an overcautious view as to the potential impact of losing exports, especially to Europe, when no such export is actually threatened (Paarlberg 2008; Gruère and Sengupta 2009a).

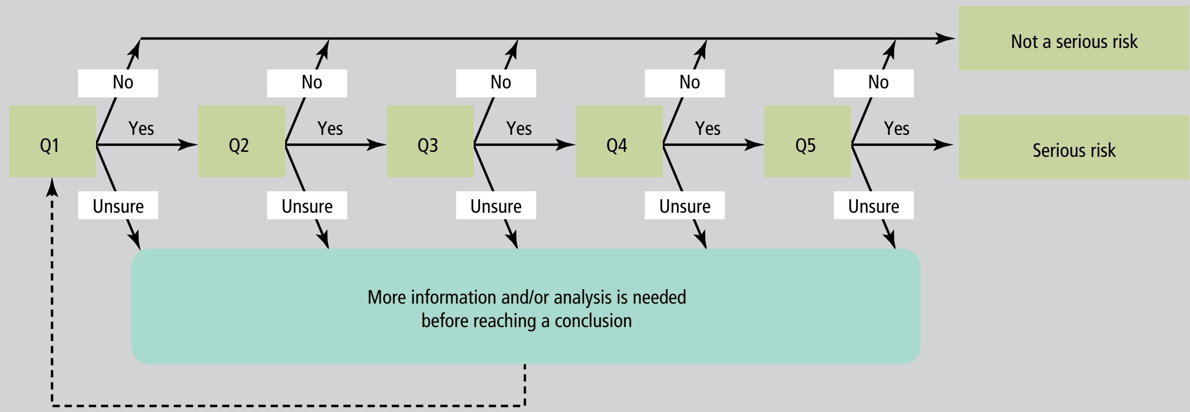
Gruère and Sengupta (2009a) discussed why, despite the lack of observable market risks, the fear of export loss is still an effective barrier to the use of agbiotech in developing countries, especially in SSA. They found that traders and buyers likely play a significant role in pushing policymakers to stay away from GM commodities by engaging in special-interest politics. They further differentiate three categories of potential export risks by their degree of legitimacy and argue that cases in which decisions were made to prevent the use of GM crops despite no trade risks arise due to asymmetric information and risk aversion on the part of policymakers. They agree on the need for a case-by case assessment of potential export risks. Such an assessment could be done using a decision tree with five dichotomous questions, as shown in Figure 6.

On the issue of what regulations African countries should adopt, one has to differentiate import authorization (for products intended for direct use or processing) that are part of biosafety frameworks from marketing regulations, such as those for GM food labeling (see Gruère 2006a). In the first case, practical guidelines have been developed at the international level under the Codex Alimentarius Commission that provide a set of scientifically well-recognized requirements and have been adopted with specificities by a number of countries. Regulations are most often based on a case-by-case review of potential consumption risks (Carter and Gruère 2006). But with the accumulation of new GM crop events in current and past pipelines, countries setting up their regulations are increasingly moving toward the recognition of approvals in foreign markets as a premise for accelerating the approval of previously developed and widely used GM products (Vietnam, under discussion for Nigeria).

Even with such procedures, the facts that import authorization often takes a longer time than the release of a new GM event in major exporters; that specific GM events are mixed together in shipments, creating the low-level presence (LLP) of unapproved GM; and that importing countries generally have zero tolerance for unapproved GM events create a risk of trade disruption. To cope with this phenomenon of "asynchronous approvals," in 2008 the Codex Alimentarius Commission adopted the "Guideline for the Conduct of Food Safety Assessment of Foods Derived from Recombinant-DNA Plants: Annex III" (Codex Alimentarius 2003) regarding the LLP of unapproved GM events approved at exporters but not yet at importers (LLP Annex 3 of the Codex). This annex was included to accelerate the process and minimize trade disruptions. To facilitate the implementation of Annex III, on July 13, 2013, FAO launched the GM Food Platform, an online database (FAO 2014a). The database provides specific information about GM plants from countries that have already done safety assessments that can be used by importing countries for the application of LLP Annex III. The decision to treat imports as LLP still relies completely on the importing country (Jank and Rath 2014). To date (April 2014), the FAO Food Platform database has 203 entries.

As African countries set up their regulatory systems, they will need to consider using a non-zero-tolerance level for GM products not yet approved, but present at low levels in traded shipments, to avoid costly trade disruption. A few studies (for example, Gruère 2011b; Kalaitzandonakes 2011) have shown that maintaining

FIGURE 6 A decision tree for export risk determination: Five critical questions



Source: Gruère and Sengupta (2009b).

Note: The questions to be asked are as follows: Q1—Is the alleged risk substantiated? Q2—Are export losses likely with the decision? Q3—Are the presumed export losses nonnegligible for the country? Q4—Is the risk unavoidable? Q5—Is the risk greater than the benefits?

zero tolerance could cost millions of dollars more than maintaining systems with a few percentage points of tolerance for GM products.

Asynchronous approvals could also affect Africa's exports to trade-sensitive markets due to the risk that a commodity shipment can be rejected at the port of entry of a trade-sensitive market. Exporting countries need to be able to ensure and even guarantee that their shipments do not have an unapproved event, especially if the importing country has a 0 percent threshold for unapproved events in its jurisdiction. Even if the developer does not intend to export to any country outside the country of jurisdiction, it may be forced to obtain approvals for products of their national research systems in trade-sensitive countries because of the possibility of commingling and thus the adventitious presence of the unapproved event. As mentioned above, the amount of trade from Africa to sensitive markets has been relatively small. Yet this may be an issue for some countries that do have specific sectors that have trade with sensitive markets, especially those that may have private contracts with buyers with standards that go beyond those included in trade laws and regulations in the importing country.

The Role of International Agreements

Beyond domestic regulatory choices, international considerations matter. Several major agreements affect international GM introduction (Gruère 2006a), but the most critically relevant, besides the guiding rules provided by the Codex Alimentarius, are the CPB and the WTO agreement.

The CPB was ratified by almost all of the African countries. It introduced a number of environmental rules to be applied preceding the introduction of new GM organisms but also created rules for GM products intended for direct use or processing that can be viewed as new trade regulations. In the specific case of commodity trade and of all products destined for food or feed for processing (FFP), the CPB provides specific expedited procedures for the evaluation of FFPs. Several of these rules, adopted or proposed under the auspices of environmental measures, may be trade distorting and could be in conflict with international obligations of member countries of the WTO (Gruère 2006a). In particular, the CPB allows countries to reject imports without any scientific reason, which could create tension with the Sanitary and Phytosanitary (SPS) agreement. Even abstracting WTO compliance, proposals related to information requirements for traded shipments (Article 18.2.a), which have been largely supported by African countries, although not very useful (Gruère and Rosegrant 2008), have been shown to create significant costs and price effects for importing African countries (Kimani and Gruère 2010; Bouët, Gruère, and Leroy 2011).

Although the WTO does not provide any specific mandate for GM regulations, the regulatory choices of WTO members need to comply with certain obligations (Gruère 2006a). In particular, the SPS agreement and the Technical Barriers to Trade (TBT) agreement provide a set of guidelines as to whether domestic regulations may or may not be WTO-compatible. Among others, import regulations for GM food cannot restrict trade for safety reasons without a scientific grounding (SPS), and technical standards for things such as labeling should be justified and be the least trade-distorting options. Furthermore, the most-preferred-nation and national treatment clauses set limits as to inconsistencies in national regulations: domestically produced GM products from all origins have to be treated the same way. In 2004 Argentina, Canada, and the United States launched a WTO dispute against the regulations of the EU that restricted imports of GM corn. Although the EU-wide process was not affected per se, the Dispute Settlement Body ruled against certain EU members' national rejection of EU decisions. Despite this result, most EU members continue to make unilateral decisions that are not based on the EU's own decisions.

On the other hand, regional bodies within Africa that are perhaps driven more by internal interests have started efforts to combine biosafety regulations with nondistorting trade policies. Many of the African biosafety harmonization efforts discussed earlier could potentially affect trade. Those involved with the aforementioned RABESA initiative have been discussing different types of harmonization schemes for GM seeds, GM products, and GM food aid that would facilitate rational trade-related regulations, harmonize scientific requirements, and avoid market disruption for GM products. In West Africa, ECOWAS and WAEMU are discussing a similar scheme to move toward integrated approval for imports of commodity products while letting each country decide on approvals for planting. These efforts underline the facts that (1) borders will be crossed, (2) replicating import approvals may not be necessary, and (3) trade restrictions can be costly (as found in a study of Bt cowpeas, Langyintuo and Lowenberg-DeBoer 2006). Efforts in southern Africa (SADC) have not been as successful as those mentioned for West Africa due to large differences in political positions around the use of GM crops.

Labeling GM Products: A Contentious Issue

In contrast to import regulations, the case for marketing regulations that are not safety related is much more debatable (Gruère 2006a; Gruère 2011a). Mandatory labeling of GM food, although adopted in many countries, has not been properly implemented in most developing countries (Gruère and Rao 2007) and is therefore not having the intended affect in those countries. Unlike import authorizations, GM labeling is not supported by any international agreement; after 15 years of debates, in 2011 the Codex Alimentarius Commission produced a text that does not provide any guidance on the use of labeling because of irreconcilable differences among countries. In the absence of international standards, and because of their potential trade-distorting effects, strict mandatory labeling regulations remain subject to possible WTO trade disputes.

Still, many countries in Africa, perhaps pushed by the African Model Law or by their relationship with countries that have labeling (Gruère, Carter, and Farzin 2009), have expressed their intention to introduce mandatory labeling of GM food despite the very limited share of packaged food products in their markets and basic, if any, food labeling regulations.

The feasibility and enforcement of their intended regulations will determine whether labeling makes any difference for consumers and whether costs are justified. A recent study conducted in India argues that in the presence of disorganized markets, GM labeling of packaged products would simply be unenforceable (Bansal and Gruère 2010). More important perhaps, the claim that GM labeling enhances consumer choice is not easy to verify (Carter and Gruère 2003), nor is it valid when compared to voluntary labeling systems (Gruère, Carter, and Farzin 2008). In markets in which a mandatory labeling system has been implemented, there are still very few GM-labeled products if any, and consumers can buy only non-GM products (for example, see Gruère 2006b). Whether this disappearance of GM products is completely or partially due to labeling remains debatable (Golan and Kuchler 2011), but the result is the same—labeling has not provided additional consumer choice or additional meaningful information.

Labeling could also have been driven by domestic consumer concerns; there is very limited evidence demonstrating lack of acceptance of GM products by consumers in Africa. Still, the general conclusions of these studies are that consumers have a low awareness of biotechnology, that respondents seems to accept the use of GM food, and that high-income urban consumers in Africa have a lower acceptance of GM food than rural consumers (for example, see Kikulwe, Wesseler, and Falck-Zepeda 2011). All consumers are willing to buy GM maize at the same price as non-GM maize, even if there are some concerns, and environmental concerns are found only among urban consumers (Kimenju and De Groote 2008). Gbègbèlègbè et al. (2009) find that rural consumers in Benin, Niger, and Nigeria, who tend to be farmers, would be willing to pay more for GM cowpeas than for non-GM cowpeas. In contrast, urban consumers are less willing to buy GM cowpeas. In South Africa, a study run by the Ministry of Science and Technology on consumers' perceptions of biotechnology found that 75 percent of the respondents were uninformed about biotechnology (Durham 2009).

Yet if consumers are unaware and generally accepting, the food industry may not always share the same opinion. Bett, Okuro Ouma, and De Groote (2010) show that Kenyan maize millers and supermarkets are more skeptical than consumers of the possible use of GM food. Most would prefer assessing GM food on a case-by-case basis before purchasing or selling these products. For some of the larger commercial actors, this perception may be related to the great reluctance of buyers abroad to use GM food. As noted above, there is evidence that GM-free private standards set up by large importing companies in Europe and other developed countries influence traders' decisions and indirectly some policy decisions around biotechnology in African countries (Gruère and Sengupta 2009a).

BOX 6 Definitions

Segregation refers to maintaining separate handling of genetically modified (GM) crops to avoid commingling with non-GM crops during planting, harvesting, loading and unloading, storage, and transport.

Traceability is the ability to maintain credible identification of a product through various steps in the farm-to-retail chain, including production, processing, and retailing, as well as its national origin.

Identity preservation is defined as the more stringent handling process requiring strict separation maintained at all times. Identity preservation lessens the need for additional testing and lowers the liability and risk for growers and handlers of GM products.

Source: Falck-Zepeda (2006).

Segregation, Traceability, and Identity Preservation (STIP) Concepts

The presence of countries with marketing specificities and non-GM market requirements has created a demand for non-GM crops, leading to an increase in the attention given to the segregation and identity preservation of GM food (Box 6). Furthermore, the EU requires not only labeling but also traceability of any imported GM product. All countries that have exports of agricultural products to EU members and other trade-sensitive countries may have to take this issue into account when considering the potential impacts of GM technology approvals for a specific product. In some cases, exporting countries will need to be prepared to bear the additional costs of implementing STIP systems.

As noted above, a number of countries have introduced voluntary or mandatory labeling regulations for GM and for organic foods and have pursued organic production systems (see Table 14 and Gruère and Rao 2007). Some countries have approved GM crops for commercial planting and at the same time have organic production systems in place. Other countries not shown in the table, such as Canada and the United States, have extensive cultivation of GM, conventional, organic, and specialized niche market productions coexisting in a systematic manner. The issue at hand is the establishment of sensible labeling and alternative production regulations that anticipate the possibility of allowing private contracts and voluntary guidelines for implementation. This will reduce the possibility of introducing production-distorting regulations and will foster coexistence between production systems that may exploit niche markets and other production possibilities.

STIP systems do have a cost associated with them. Cost estimates from the literature for STIP systems range from a few percent to 25 percent over the cost of conventional products (for example, see Smyth and Phillips 2002; Gruère 2009). For instance, South Africa's commercial segregation cost for non-GM maize was around 5 percent in 2007 (Gruère and Sengupta 2010). The costs for high-volume or noncommercial systems can be significantly higher than these estimates, and in some countries they may exceed the benefits of adopting the biotechnology innovation.

The experience with assessing the potential impact of labeling, STIP, and coexistence systems in developing countries is quite thin. A study by De Leon, Manalo, and Guilatco (2004) estimated the costs of GM food labeling to all stakeholders in the Philippines. Estimates were produced for GM soybeans and maize in the country. A mandatory labeling law would imply additional production costs that varied between 11 and 12 percent of additional costs, expected to be passed on to consumers.

Therefore, if a developing country (such as one in Africa) wants to deploy a GM product that will require a STIP system, it needs to be cognizant of the significant additional costs of implementing such a strategy. An important recommendation would be that the benefits of the biotechnology innovation be higher than the costs of the required STIP system. Furthermore, the net benefits will need to be equally distributed along the food chain so that in the end no one is made worse off through the introduction of any GM technology.

TABLE 14 Biosafety, labeling, biotechnology, and organic agriculture status of selected countries of Asia and Africa, 2007

COUNTRY	STATUS						
	Member of the Cartagena Protocol on Biosafety	Confined field trials	Commercial approvals for planting	Labeling status	Threshold for labeling	Area planted in certified organic production, 2006 (hectares)	Share of organic production as a percentage of total agricultural land
Africa							
Burkina Faso	Y	Y	Y	6	n.t.	30	<0.01
Egypt	Y	Y	Y*	6	n.t.	24,548	0.72
Ghana	Y	N	N	6	n.t.	19,132	0.13
Kenya	Y	Y	N	5	n.t.	182,438	0.69
Mali	Y	N	N	6	n.t.	170	<0.01
Senegal	Y	N	N	6	n.t.	2,500	0.03
South Africa	Y	Y	Y	2#	n.t.	45,000	0.05
Tanzania	Y	Y	N	6	n.t.	55,867	0.14
Uganda	Y	N	N	6	n.t.	122,000	0.99
Zambia	Y	N	N	7	n.t.	187,694	0.53
Zimbabwe	Y	Y	N	7	n.t.	1,000	<0.01
Asia and Oceania							
Australia	NP	Y	Y	2	1	12,126,633	2.71
China	Y	Y	Y	1	1	3,446,570	0.6
India	Y	Y	Y	5	n.a.	114,037	0.06
Indonesia	Y	Y	Y*	4	5	52,882	0.12
Japan	Y	Y	N	2	5	29,151	0.56
Philippines	Y	Y	Y	4	n.a.	14,134	0.12
South Korea	Y	N	N	2	3	28,218	1.46

Sources: Willer and Yussefi (2005); Gruère (2006a); Viljoen, Dajee, and Botha (2006); Gruère and Rao (2007).

Note: Y = Yes; Y* = temporary approval later withdrawn or not yet pursued; N = No; NP = nonparty; 1 = stringent mandatory; 2 = pragmatic mandatory; 3 = voluntary for substantially equivalent foods; 4 = mandatory, introduced but not implemented; 5 = expressed intention to introduce labeling; 6 = no clear position; 7 = no labeling required; n.a. = not applicable; n.t. = no threshold in place; # = transitioned from voluntary to mandatory labeling in 2011.

One important policy question is whether countries may implement mandatory or voluntary labeling regimes and thus in some cases require the implementation of STIP systems. Lapan and Moschini (2004) examined the trade implications of GM products in light of voluntary and mandatory labeling systems in a two-country model. In their model, GM products are viewed in one of the countries as an inferior commodity, and thus may be at most equivalent—but usually inferior to—conventional products. Their model shows that the welfare of some of the participants in the market may be improved under some conditions, whereas other participants may be made worse off.

An additional significant finding of the authors' theoretical model is that the mandatory labeling of GM products (as implemented by the EU) is unnecessary and inferior to a system of voluntary labeling. Furthermore, mandatory labeling has significant costs for the exporting country, which is forced to implement a segregation and identity preservation system behind the label. Curiously enough, their model showed that the importing country may benefit from lowering the price of GM-free goods. They recommend additional analyses of identity preservation systems at the international level and a further examination of the labeling costs and distribution in developing countries.

Carter and Gruère (2003) argue that a mandatory labeling system does not give a choice to consumers in the EU. Retailers and processors have reacted to consumers' perceptions by almost completely restricting the supply of "GM" food products. A voluntary labeling system, in contrast, would allow a choice provided that consumers' willingness to pay for non-GM products exceeded the price premium for such products.

Food Aid Controversies

Several countries in Africa and elsewhere have introduced bans, moratoriums, and in some cases restrictions on the importation of GM-containing food aid or commercial trade in grains for human or animal consumption (Table 15). In particular, the well-publicized 2002 decision of Zambia to reject food aid with GM grains, even milled, at a time of famine was highly controversial (Zerbe 2004; Paarlberg 2008). Although the safety of Zambians was invoked, several reports have revealed that the decision was largely driven by considerations of export to Europe (Gruère and Sengupta 2009a). More recently, in the summer of 2011 in eastern Africa, Kenyan parliamentarians debated the importation of GM maize from South Africa, opposing the perceived risks of paying 30 percent more for non-GM maize at a time of severe shortage, despite having imported South African maize for years (Kimani and Gruère 2010).

In other instances the ban, moratorium, or restriction was due to fears that unmilled grain might be planted and thus affect external trade, especially with Europe. If these countries continue to have external trade with countries that do not want GM maize, they may have to preserve information through well-defined identity preservation and segregation systems, testing, and labeling of their imports and exports. These systems tend to be expensive, may increase the costs of production, and may make the implementing country's products less competitive in international markets and thus have an impact on food security.

The food security and economic development problems faced by some developing countries, particularly in SSA and in Southeast Asia, imply that these countries need to evaluate all trade-offs in great detail. They need to choose between using biotechnologies that may address food insecurity or trade and the implementation of costly STIP and labeling systems in-country.

NATURAL RESOURCE MANAGEMENT (NRM) AND BIODIVERSITY

Many of the concerns over the adoption of agricultural biotechnology are associated with the potential impacts on the environment and, in particular, the impacts on biodiversity and natural resources. The CPB was developed under the Convention on Biological Diversity precisely because of concerns about the potential for GM organisms to negatively affect the conservation and sustainable use of biodiversity. The concerns include the potential for a loss of biodiversity due to interactions between the GM organisms and the environment, including gene flow from GM plants at centers of origin, and the impacts of GM plants on other organisms in their surroundings. Other concerns are associated with possible changes in agricultural practices, such as land use patterns or the adoption of monocultures. Although these possible impacts are considered before regulatory decisions are made in every country, there are some questions about whether the potential for environmental impacts might be different in African countries and whether these countries have the capacity to manage such risks when they exist.

Concerns about Biodiversity and Centers of Origin

To date, there is no evidence of negative consequences for the environment from growing GM crops. Much of the information that has been used for risk assessments elsewhere would be applicable in African countries. This is particularly true for Bt crops, for which there is a wealth of information about the mode of action and the specificity of the proteins that these crops are modified to produce (Sanvido, Romeis, and Bigler 2007). However, certain aspects of the environmental risk assessments are dependent on the biology of the crop plant that has been modified and the environment where the crop will be grown. Some crop plants, such as sorghum, cassava, and bananas, are being modified specifically for use in African countries and may not be approved for use elsewhere before they are considered by African regulatory authorities.

In these cases, the possibility of gene flow from these crops to other compatible plants will need to be

TABLE 15 Limits on genetically modified (GM) product use in select African countries, 2013

COUNTRY	LIMITS ON USE	YEAR INTRODUCED OR REPORTED	LIFTED OR EXPIRED
Algeria	Ban on distribution and commercialization of GM products[b]	2000	—
Angola	Ban on GM foods except for milled grain[a]	2004	—
Benin	Two five-year moratoriums	2002	Expired
Botswana	Ban on GM imports, except for milled GM food aid	2002	Lifted
	Strict liability in place	2006	
Egypt	Ban on GM imports and exports	2009	
Ethiopia	Ban on GM foods except for milled grain[a,b]	—	
	Strict liability regulations	2009	
Kenya	Ban on GM imports	2012	
Lesotho	Ban on GM food except for milled grain, which comes with a government advisory that it is to be used only for food, not cultivation[a,b]	—	—
Madagascar	Ban on GM foods except for milled grain[a,b]	2002	—
	Ban on GM imports and cultivation	—	
Malawi	Ban on GM foods except for milled grain[a,b]	2002c	Lifted
Mozambique	Ban extended even to nonmilled food aid products[a]	2002c	Lifted
Namibia	Ban on GM imports	2002	Lifted
Nigeria	Ban on nonmilled food aid products	—	Lifted
Sudan	Temporary waivers for GM food aid imports	2003	Lifted
Swaziland	Ban on GM foods except for milled grain[a,b]	2002	Lifted
Tanzania	Ban on GM foods except for milled grain[a,b]	2002	Lifted
	Strict liability regulations	2009	
Zambia	Ban on GM imports and GM food aid	2002[c]	Lifted
Zimbabwe	Ban on GM imports (with 1% tolerance for maize and soybeans)	2002[c]	Lifted
	Identity requirements for non-GM	—	

Sources: Falck-Zepeda (2006); Gruère and Sengupta (2010).
[a]AGRA (2013).
[b]UNEP (2006).
[c]Zerbe (2004).
Note: Dash = data not available. In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

considered, especially when these crops will be grown near their centers of origin, for example, in the case of sorghum, in Africa (Hokanson et al. 2009). There is an increased opportunity for gene flow at centers of origin because it is more likely that compatible plants will be found in proximity to plantings of the crop. In fact, gene flow commonly occurs between non-GM crop plants and their wild relatives wherever the crops are grown in proximity to other compatible plants. Where this is the case, the risk questions will focus on the possibility that the new trait in the GM crop could lead to a negative impact on the diversity of that crop species, including landraces or closely related species, or on the diversity of other organisms in the surrounding environment that would be exposed following gene flow. These assessments are not necessarily complex and can be straightforward, especially when the introduced trait does not alter the fitness of the plant in any way or is not intended to control another organism, such as a pest. Still, when African countries are faced with decisions about these crops, they will require the capacity to consider these risks in their decisionmaking. Building African biosafety capacity to conduct or evaluate environmental risk assessments will be important in addressing these issues.

Likewise, the possibility of a potential impact on other organisms that are found in the African environment where these crops are grown will need to be considered by determining which organisms are likely to be exposed and to which organisms the introduced trait might present a hazard (Romeis et al. 2008). African regulators need a clear understanding of the protection goals set forth in their laws and legislation related to GM organisms, particularly regarding the protection of any species that are rare, endangered, or protected. Of course the negative impacts of chemical pesticide sprays on organisms in the environment and on human health in these African countries, where caution with chemical pesticides is not well enforced, should be compared to any possible similar impacts of GM crops. There is likely to be significantly less impact from GM crops.

Additional concerns associated with NRM and biodiversity in African countries are related to possible changes in land use or the use of these crops in monocultures. These concerns are prompted by observations of modern agriculture, including the use of GM crops, in the developed (especially Western) world, which have favored specialization and monoculture (Holmen 2006). Farming systems in Africa are quite different from those in Western agriculture, and the availability of new GM varieties is not likely to significantly change the farming systems on the continent. However, how best to balance the need for increased food production with the need to conserve natural resources is a challenge for African countries. A recent study considered the question of how to meet rising food demand at the least cost to biodiversity by evaluating two contrasting alternatives: "land sharing," which integrates both objectives on the same land, and "land sparing," in which high-yield farming is combined with protecting natural habitats from conversion to agriculture (Godfray 2011). Using India and the African country of Ghana as models, that study found land sparing a promising strategy for minimizing the negative impacts of food production at both current and anticipated future levels of production. This should be true regardless of the variety of crop plants that are grown, and it holds an important message for sustainable use and the conservation of biodiversity in Africa in the face of the ever-increasing need for food production.

It should be noted that myriad benefits in this regard are now being documented from the use of GM crops in other countries; these benefits should be weighed in the decisionmaking of African countries (Brookes and Barfoot 2005; James 2007; NRC 2010). There is evidence that these crops actually represent a land-saving technology and, furthermore, reduce the environmental footprint by more efficiently using external inputs. There is evidence of fewer insecticide and herbicide sprays, with the associated human health and economic benefits. These crops have the potential to mitigate climate change in the future by offering more adaptive crops or germplasm for growing and breeding, and also to optimize carbon sequestration, lower the levels of greenhouse gases, and provide for more cost-effective production of environmentally friendly biofuels. Because SSA is experiencing faster degradation than any other region of many environmental resources important to poor people (including land degradation, desertification, biodiversity loss, deforestation, loss of arable and grazing land, declining soil productivity, and the pollution and depletion of fresh water) (Commission for Africa 2005), African countries should consider how adopting the products of biotechnology into their agricultural systems could increase, not decrease, the sustainable use and conservation of biodiversity (Tait and Barker 2011).

Risk Management and Smallholder Farmers

In the United States a role has been identified for appropriate on-farm management in order to protect the viability of traits inserted into GM crops (NRC 2010). Because agricultural systems in Africa are different from those in Western agriculture, where GM crops have been mainly adopted, some elements of risk may need to be reconsidered when these crops are grown in African countries. The best example is seen in the significant efforts that are being made in the United States to stop or slow the evolution of insect pests' resistance to the pesticidal activity that has been introduced in Bt crops (Bates et al. 2005). This concern is largely due to the fact that the same proteins from the Bt bacterium that were introduced into the Bt crops are used in spray formulations of the bacterial spores. Insect resistance would mean that the GM crops would no longer be effective against the insect; moreover, if the insects developed resistance to the proteins used in the bacterial spray formulations, it could result in the loss of an insecticidal spray that is a favorite among organic growers and home gardeners. In Africa, similar concerns about the development of insect resistance would be focused mainly on the loss of the newly adopted GM crop as a tool for insect control, especially among small-scale farmers, not on the loss of the Bt insecticidal sprays because they are not commonly used there.

This concern over potential insect resistance to the Bt proteins has prompted a significant amount of research on the topic, which is continuing today. Based on the results of that research, specific policies have been put forth by the US regulatory agencies for the use of Bt crops, and the technology providers have implemented mandatory insect-resistant management schemes for the use of their products. Consequently, developing countries that have adopted these Bt crops, and those considering them, should consider the need for similar strategies for insect resistance management. Questions have been raised about whether different strategies could be implemented in these countries or whether they should be necessary at all. For example, in these countries, where the agricultural landscapes are more diverse, it might be possible to rely on natural alternative hosts of the insect pests rather than requiring the planting of non-GM plants where the GM plants are planted (a refuge strategy). The best strategy for the African countries, including the possibility of no strategy, needs to be determined.

Beyond the best strategies to avoid insect resistance, there are concerns about the feasibility of implementing any mandatory management strategies in African agricultural systems. Because much of African agriculture is in the hands of smallholder farmers, the education and communication requirements of any risk management strategy are significant. For the Bt crops, alternative refuge schemes such as a "bag-in-a-bag" (whereby the GM seed is mixed with an appropriate percentage of non-GM seed before sale of the seed) have been proposed, but this type of refuge may or may not be effective to slow resistance evolution. Enforcing a refuge strategy would require an intensive effort. In the United States, technology providers are also working on strategies to introduce more than one pesticidal gene, with different modes of action against the same pest, into a single crop. The "stacking" of pesticidal genes in this way is very effective in slowing the evolution of insect resistance. Although this holds promise as an advanced approach to insect resistance management, it is not certain that this advanced application of the technology will make its way from the technology providers into the hands of African farmers, especially for non-commercial crops.

Implementation of risk management for GM crops, when the need has been identified, will continue to be a challenge in African countries. However, this is the same challenge that agricultural production in Africa faces now, using traditional varieties. Smallholder farmers need to be educated about the best farming practices. Proper stewardship of the technology by the technology providers could go a long way toward alleviating this concern with GM crops, but it will require a significant and concerted effort by the technology providers and the African regulatory authorities in order to be effective. Issues with respect to stewardship management of and education regarding publicly developed or public-good crops remain. Furthermore, a combination of technical approaches and supportive policies may be needed, especially for public-sector crops.

Politics, Communication, and Outreach

THE ROLE OF DONORS

Donors' presence and funding for African agriculture varies across countries and organizations. According to the Agriculture Science and Technology Indicators (ASTI) collected by the International Food Policy Research Institute (IFPRI), there are several sources of donor funding. The donor landscape in Africa can be divided into multilateral bodies such as the EU, CGIAR, and the United Nations. Examples of bilateral donors are agencies of individual governments such as the US Agency for International Development (USAID), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the UK's Department for International Development (DFID), the EU Framework Programmes, the Swedish International Development Cooperation Agency (SIDA), the Canadian International Development Agency (CIDA), the Australian Agency for International Development (AusAID), and the Australian Centre for International Agriculture Research (ACIAR) and private foundations and philanthropic organizations such as the Bill and Melinda Gates Foundation (BMGF), the McKnight Foundation, Syngenta Foundation for Sustainable Agriculture, the Rockefeller Foundation, and the Carnegie Corporation. There are also subregional organizations such as the Forum for Agricultural Research in Africa (FARA), the Conference of African and French Leaders of Agricultural Research Institutes West and Central African Council for Agricultural Research and Development (CORAF/WECARD), and the Association for Strengthening Agricultural Research for Eastern and Central Africa (ASARECA), which in turn receive their donations from multitrust funds operated by multiple donors. Finally, multilateral development banks such as the World Bank and the African Development Bank (AfDB) also provide loans and grants for agriculture (Beintema and Stads 2011).

Donor funding has been the backbone of support for a large number of projects in agriculture, for both research and development (R&D) and agribusiness organizations, in many African countries. As in the case of financing and investments, information on donor activities specific to agriculture biotechnology (agbiotech) is not always disaggregated and therefore is difficult to fully assess. A survey of projects involving genetically modified (GM) crops supported by European donors from 2001 to 2010 reveals that most of these dealt with food and environmental safety versus R&D on GM crops themselves (European Commission 2010).

Morris (2011) provides a crop-specific list of R&D biotechnology. According to her report, funding for these projects comes from various kinds of donors and includes bilateral government funding as well as private-sector funding from the United States. On the other hand, most of the investments by multiagency private funds in agribusiness seem to come from donors based in Europe.

At the 2009 L'Aquila summit of the Group of Eight (G8), US$22.5 billion was pledged to combat hunger and provide food security in Africa, including US$3.5 billion from the United States and US$3.8 billion from the European Commission (EC), as well as significant commitments from several other European donors (Montpellier Panel Report 2010).

The European contribution is being channeled through EU programs that are supported by the European Development Fund and the Food Security Thematic Programme (FSTP), which was created in 2007 to address food security at the global, continental, and regional levels. Its annual average budget was €241 million (US$325 million) for the years 2007–2013 (Welcome Europe 2014). In 2008 the EC also pledged €1billion to bridge the gap between emergency aid and medium- to long-term development aid in 32 African countries (Montpellier Panel Report 2010). A new EU Policy Framework to Assist Developing Countries Address Food Security Challenges was issued in 2010. This calls for a 50 percent increase in funding to agricultural research, extension, and innovation by 2015 (Montpellier Panel Report 2010).

The US initiative, the Feed the Future (FTF) program, was launched in May 2010 in response to President Barack Obama's pledge of a starting fund of US$3.5 billion for agricultural development and food security over three years. The intention is that the program will help to leverage more than US$18.5 billion from other donors in support of a common approach to achieving sustainable food security.

In 2012 the G8 initiative New Alliance for Food Security and Nutrition was launched. This is a joint initiative of African leaders, the private sector, and development partners to invest in agriculture in Africa with the objective of lifting 50 million people out of poverty. It supports the Comprehensive Africa Agriculture Development Programme and works in collaboration with the Grow Africa partnership, NEPAD, and the World Economic Forum. G8 commitments for 2012–2015 were US$3.95 million for six countries (Burkina Faso, Côte d'Ivoire, Ethiopia, Ghana, Mozambique, and Tanzania), and, as of April 2013, 91 percent of these resources had already been committed (New Alliance 2013).

The Global Agriculture and Food Security Program (GAFSP), managed by the World Bank, is also an example of a multidonor trust fund, comprising donors from both the United States and the EU. Commitments from 10 donors up to December 2013 amounted to US$1.3 billion over three years, of which US$1.2 billion had already been received by December 2013 (GAFSP 2014).

Donor countries' perceptions of biotechnology also affect the types of agreements that are developed with countries in Africa. For example, in association with Argentina, Brazil, India, and the United States, the Department of Science and Technology in South Africa identified biotechnology as one of the priority areas for science and technology development in the country. Meanwhile, an agreement between Norway and South Africa's Department of Environmental Affairs is focused on environmental risk assessment of the impacts of genetically modified organisms (GMOs) postcommercialization. This agreement, which involves a Norwegian regulatory capacity-building nongovernmental organization (NGO), Genok, is interesting in that Norway has no domestic experience with commercial GM crop cultivation and lacks a government policy on the application and use of biotechnology (Morris 2011).

However, there are some examples of multiagency funding for agriculture in Africa and other developing countries that feature the joint cooperation of donors. The above-mentioned GAFSP is an example of one such program. It is funded by the governments of Australia, Canada, Ireland, Korea, Spain, and the United States, as well as BMGF. However, GAFSP has no mandate for biotechnology.

In recent years, BMGF has become a major force in donor funding for agbiotech. Major projects like African Biofortified Sorghum (ABS), Water-Efficient Maize for Africa (WEMA), and Improved Maize for African Soils (IMAS) are primarily supported by significant contributions from the foundation. Moreover, BMGF is also joining other multilateral donors to invest in other aspects of biotech in Africa. Table 16 lists some of the BMGF biotech-related grants. Although many of these grants are specifically for biotechnology or biosafety, others include nonbiotech components.

What is revealed in this discussion is the vast array of donors and projects being undertaken across various countries of Africa. Although donors' interest in agriculture and also, to some extent, biotechnology in Africa has resulted in increased R&D capacity in various countries, it is important to evaluate the duration, sources, and focus of funding across the diversity of donors to ensure that funding and projects can be sustained.

Providing support to regional networks and organizations may also represent a preferred mechanism by which to channel funding, because it can reduce duplication of effort among donors and also reduce the effects of multidonor tensions on biotechnology. In this regard, a comprehensive capacity assessment conducted under the auspices of the AfDB could be valuable to ensure that donors' aid is better distributed across a range of African countries and not concentrated in a select few.

COMMUNICATION AND OUTREACH

In large part, the current perceptions in Africa about GM technologies can be traced to a polarized and prolonged war of words and to a test of political wills between Western countries. The debate has been perpetuated by proponents and opponents of biotechnology from the outset, but especially during the initial US-EU dispute, when the development and adoption of new GM crops was primarily done in the United States. Although the origins of the debate run far and wide, a "Feed the World" public relations campaign launched by Monsanto in Europe in the mid-1990s resulted in a number of complaints from development organizations, civil society, and activists alike, arguing that any implication that biotechnology was the silver-bullet solution to the problem of world hunger was a gross oversimplification. Even louder arguments ensued around the premise of some that biotechnology was a technology of the rich that could cause irreparable harm to human health and the environment. This debate was summarized by Altieri and Rosset (1999) in "Ten Reasons Why Biotechnology Will Not Ensure Food Security, Protect the Environment, and Reduce Poverty in the Developing World," to which McGloughlin (1999) responded in "Ten Reasons Why Biotechnology Will Be Important to the Developing World." These opposing views were thrust into the center of this debate, resulting in a legacy of polarized and constant argument.

At the time, Africa's role in biotechnology was being influenced by others. The technology development and its initial application had not reached the continent, and policymakers, scientists, country leaders, and communities were not well equipped to participate in the discussion in a substantive way. Today, despite an increasing body of scientific and economic evidence that shows the overall benefits of biotechnology, the polarized debate continues at all levels of African society. Now the debate centers around myriad issues related not only to safety but also to concerns about food security, national sovereignty, farmers' rights, social justice, and poverty reduction. The continuing debate appears to be largely driven by the precautionary approach of European policymakers and consumers. Some claim that this position has been inappropriately exported to Africa through various channels of influence (Paarlberg 2001, 2008). The continued back-and-forth nature of the conversation has led to technological paralysis and an inability to make an informed decision among policymakers and members of the public alike across the African continent. The continuing controversy, as some would argue, has deprived the African farmer of the ability to make an informed and independent choice about which technologies to employ on his or her farm.

It can be argued that a systematic, sustained, properly resourced outreach effort should be mounted in Africa, for Africa is critical to break the stalemate of ideas, beliefs, and perceptions; such an effort would allow African policymakers to make decisions that are in the best interest of their countries. Particularly effective would be a comprehensive, balanced approach that recognizes the interdependence of seemingly disparate influencers: policymakers, country and regional decisionmakers, African institutions and scientists, farmer leaders, NGOs, and the media. Together they could form a strong coalition that would be able to address all parts of the debate in a reasonable, pragmatic manner. Treated independently through conventional outreach methods, which have been pervasive in Africa, these stakeholders will continue their polarized debate and leave decisionmakers in confusion.

Political Outreach and Political Will

Political positions taken by African political leaders have been historically divergent with respect to GM technology. Nevertheless, the importance of political engagement with respect to biotechnology cannot be underestimated, and such engagement has often been a key driver of any given country's adoption or rejection of the technology.

TABLE 16 Bill and Melinda Gates Foundation (BMGF) Africa-focused biotechnology- and biosafety-related grants, 2012

YEAR	ORGANIZATION	AMOUNT (US DOLLARS)	PURPOSE
2007	Michigan State University	1,498,485	To undertake a consultation, design, and training process to develop an African Biosafety Center of Expertise
2008	African Agricultural Technology Foundation	39,149,859	To develop drought-tolerant maize for small farmers in Africa
2008	International Centre for Genetic Engineering and Biotechnology	323,113	To develop effective safety and regulatory systems in the field of modern biotechnology
2008	Donald Danforth Plant Science Center	5,345,895	To support the creation of a biosafety resource support network for the Grand Challenge #9 projects
2009	AfricaBio	270,170	To identify the most effective means of raising public awareness of biotechnology issues in Africa south of the Sahara
2009	Michigan State University	13,294,412	To create a center in Africa that provides support for African regulators
2009	Harvard University	1,474,392	To promote the benefits of science and technology for African agriculture and endorse an independent expert report issued by the African High-Level Panel on Biotechnology
2010	African Agricultural Technology Foundation	200,000	To support conferences that enhance knowledge sharing and awareness related to biotechnology
2010	Donald Danforth Plant Science Center	8,257,560	To support the development of high-iron, -protein, and –provitamin A cassava for Kenya and Nigeria
2011	African Agricultural Technology Foundation	56,001,491	To increase the availability and accessibility of more resilient and higher-yielding seed varieties of important food crops in Africa south of the Sahara
2011	Donald Danforth Plant Science Center	5,548,750	To support work on mosaic- and brown streak–resistant cassava
2012	African Agricultural Technology Foundation	45,696,202	To develop and distribute improved maize hybrids for Africa that are drought tolerant, insect resistant, and higher yielding
2012	African Agricultural Technology Foundation	3,149,015	To enhance knowledge sharing and awareness on agricultural biotechnology
2012	African Agricultural Technology Foundation	4,200,000	To support conferences that enhance knowledge sharing and awareness related to biotechnology
2012	International Centre for Genetic Engineering and Biotechnology	6,328,737	To develop effective safety and regulatory systems in the field of modern biotechnology
2012	Donald Danforth Plant Science Center	329,150	To support a conference that is part of a triennial series of global meetings on cassava
2012	Purdue University	1,000,000	To develop a genetic and genomic resource that will assist sorghum researchers

Source: BMGF (2012).

Note: Grand Challenge is an initiative to seek "innovative solutions to some of the world's most pressing global health and development problems" (BMGF 2014).

In fact, one could argue that political will as to whether to move toward the development of biotechnology is paramount (Jeremy Ouedrago, Minister of Livestock and Human Resources, Burkina Faso, pers. comm., December 2011).

The experience of countries that have commercialized GM crops appears to confirm that political will is influenced by (1) whether country leaders and decision-makers see that the technology has the potential to benefit farmers in their countries, as was the case in Burkina Faso with Bt cotton; (2) whether local scientific institutions are equipped to be involved in the development of the technology; and (3) public opinion.

In addition to South Africa, Kenya was one of the first countries to test GM crops and to develop a functional regulatory framework. Political leaders in the country took a supportive stand for the technology early on. In a letter to US President Bill Clinton in May 2000, President Daniel arap Moi asked for US support to close the biotechnology gap, stating that "in the face of growing population and environmental challenges, current farming methods are proving incapable of meeting our requirements for food security and economic growth. It is, therefore, imperative that we in Kenya embrace appropriate technologies and policies to transform our agricultural system to become more productive and profitable. It is in this context that we must view the new developments in biotechnology as offering great hope and promise" (Cooke and Downie 2010, 12).

Shortly thereafter, one of the more notable cautious positions was taken by Zambia's President Levy Mwanawasa, who, during the 2002 food aid crisis, catalyzed a firestorm of discussion when he rejected food aid shipments that contained GM maize. Justifying the government's position, during the 2002 World Summit on Sustainable Development in Johannesburg he said, "Simply because my people are hungry that is no justification to give them poison, to give them food that is intrinsically dangerous to their health" (Cooke and Downie 2010, 6). This statement was galvanizing for many in Africa who had numerous concerns about the technology. This position also directly affected the advance of the Southern African Development Community's (SADC's) biotechnology harmonization process and altered procedures for the handling and milling of food aid originating from countries where GM crops were being grown. GM food aid concerns continue in the wake of the food security crisis in northern Kenya and Somalia and have been raised again by some key influential members of Kenya's parliament, causing upheaval in a regulatory system that had been functioning with efficiency since the passage of the Biosafety Bill in 2009. At the same time, multiple African countries have seen the potential of the technology and have steadily moved forward in developing workable policies and regulations, as follows:

- In Burkina Faso, the actions of high-level political advocates have had an equally powerful and opposite result. A potential product—Bt cotton—that would help Burkina Faso economically created high-level political interest. The Ministry of Secondary, Higher Education and Scientific Research launched a program to create awareness of the need for a biosafety law (ISAAA 2010). Subsequent passage of the law and the adoption of Bt cotton have led to well-documented benefits for the country's economy and farmers. For 2009 Vitale et al. (2010) documented an average increase of 18 percent in yield and US$61 per hectare in income, along with a 50 percent reduction in the use of insecticide sprays.

- Political leaders in Uganda have also seen the connection between products that have the potential to help them reach national growth goals and a functional regulatory system. In April 2008, Uganda's state minister of finance, Fred Jachan Omach, approved a national biotech and biosafety policy stating the significance of Uganda's being part of the advance in biotechnology agricultural and industrial research (Biovision 2008). Today, six years later, Uganda has more potential biotech products undergoing evaluation than any other country in Africa except South Africa.

- Similarly, Malawi President Bingu wa Mutharika, while chairing a cabinet meeting at which Malawi's National Biotech Policy was approved, recognized the pivotal role that biotechnology could play in contributing to poverty reduction and economic growth (Karembu, Nguthi, and Ismail 2009). In November 2012 the Malawi government approved its first GM confined field trial (CFT).

- In 2008, the African Technology Policy Studies Network reported, "Liberian President Ellen Johnson Sirleaf reminded delegates at the Science in Africa Summit that: 'No country on Earth has developed without harnessing and utilizing science and technology, whether through technology transfer or home-grown solutions'" (ATPS 2010, 36).

- In October 2010, at the Fifth Meeting of the Conference of the Parties of the Cartagena Protocol on

Biosafety, Kenya's minister for science and technology, William Ruto, argued that some Western countries had no moral authority to block the use of GM crops (GMO Safety News 2010).

These more GM-favorable positions were likely triggered by a number of factors, including the availability of accurate information about the safety of biotechnology, the matching of farmers' needs with vocal farmer leaders, the participation of country institutions and scientists in the conversation and the research, a few well-informed media outlets, and public participation in the conversation.

As is the case of most outreach efforts for biotechnology in Africa, outreach to high-level policymakers has been sporadic and not well informed by a strategic approach. Typically conversations have taken place as bilateral discussions between governments or between governments and key stakeholders (for instance, the biotechnology industry or NGO civil-society action groups). Outreach to elected officials at both national and local levels, as well as to high-ranking members of the bureaucracy, should be a priority. Constituency needs and sensitivities with respect to varying positions should be considered in any pursuit of this political engagement strategy. Discussions about biotechnology have also taken place within the context of the African Union (AU), leading to the following:

- The 2001 development of the African Model Law on Safety in Biotechnology by the Organization for African Unity, discussed in more detail above.
- The 2005 establishment of the High-Level Advisory Panel on Modern Biotechnology.
- The 2006 African Position on Genetically Modified Organisms in Agriculture, which rejected the patenting of life forms, articulated the rights of nations to declare GMO-free zones, and endorsed the "precautionary principle" as the guiding directive for biosafety. This position, in particular, reflects an EU position, affects African regulators' response, and has influenced the attitudes of high-level policymakers (Kimenju et al. 2011).

In light of an additional eight years of experience with GM crops in Africa since this 2006 African Position and the evolving experience with GM crops in a growing number of African countries, this might be a good time to re-examine the current stance and position statements of the AU. The African Science Academies (ASA) recently issued a declaration in support of the responsible use of GM technologies. Specifically, ASA upholds the idea "that biotechnology-enhanced tools and products can play a significant and positive role in meeting Africa's dire need and persistent challenge to break the seemingly perpetual cycle of hunger, malnutrition, and underdevelopment" (ASA 2013, 3). These new developments can open a viable avenue by which to develop further awareness of the issues involved and move toward a more balanced position for the continent as a whole.

Outreach to the Public, NGOs, and Civil Society

There appears to be a discord in the debate among members of the general African public and those who have influence with decisionmakers. Yet it seems that few organizations have the resources or the strategic tools to change this situation in a way that can be embraced by both sides. Additionally, outreach strategies have been implemented without regard to countries' preparedness (policies), the timing of the release of relevant products, or a clear understanding of the motivations or concerns of each stakeholder. In order to avoid wasting millions of dollars without achieving meaningful results or progress, outreach activities must take into account the needs identified by different African organizations, such as the following:

- Broad public outreach. Recommendation 11 of the African Union New Partnership for Africa's Development (AU/NEPAD) report *Freedom to Innovate* of the High-Level African Panel on Modern Biotechnology unequivocally supports the need for broad public outreach. It states that "public awareness of—and public engagement in—biotechnology is needed at all levels in Africa. A lack of both will make it difficult for AU member states to individually and collectively discuss, set priorities and exploit economic and other opportunities offered by biotechnology" (Juma and Serageldin 2007, 59).
- Special advisory panels. The African Biotechnology Stakeholders Forum, an organization that argues for the responsible use of GM technology in Africa, has suggested that a way to improve communication among the different stakeholders is for private companies to experiment with advisory boards that involve citizens' groups and for the government to increase the information that is directed to the general public and also involve scientists in this dissemination effort.
- Honest brokers. Polarizing multimillion-dollar public relations campaigns have become the norm on both sides of the argument, the product development

community (both public- and private-sector developers) as well as anti-biotech groups and activists. Probiotech initiatives (a number of which are shown in Table C.7) (Karembu, Nguthi, and Ismail 2009) have tended to be more traditional, whereas anti-biotech activists and civil-society organizations appear to have favored the use of Internet outlets and social media to get their message across. What could likely advance the process would be honest brokers, a sustained effort, and a platform that is devoid of preconceptions.

The Role of African Public Institutions, Universities, and Scientists

It stands to reason that an empowered and credible scientific community that is equipped to communicate with policymakers and the public will be critically important to the success of any communications and outreach initiative (Cooke and Downie 2010).

In Kenya, where the debate about the technology has once again become polarized, former Agriculture Secretary Wilson Songa called for all scientists to become more active in the conversation to counteract the positions of some politicians who have very little scientific knowledge and have only stalled the process (Waruru 2011).

More important, African scientists, especially in countries where functional regulatory systems are in place, have gained the experience necessary to answer the most pressing questions that remain today. Biotechnology is being applied to crops of African importance, by African scientists, for Africans. The challenge has been bridging the gap between the technical knowledge of the scientists and the technical knowledge not only of some policymakers but especially of the public. There is also a fundamental difference between the way that scientists think and communicate and the way that policymakers and the general public think and communicate. Most media consumers do not typically make it past the headline of a story. Yet scientists are trained to offer supporting evidence before drawing a conclusion. Without training, this could lead to more misinformation and less confidence among decisionmakers.

Even so, in countries where scientists have received comprehensive communications training and have been tapped as resources in the biotechnology conversation by policymakers, decisionmakers, farmers, the media, and NGOs, countries' decisionmakers feel more comfortable making decisions for their country and the public has greater confidence in the decisions that are made on their behalf.

The Role of the Media

The important role of the media in shaping the biotechnology public and policy debate in Africa is without dispute. However, a more comprehensive review of how to target resources within this outreach mechanism is critical. In any given population or country, decisionmakers, policymakers, and the general public acquire information about innovations such as biotechnology through different media. For example, a study in Kenya (Kimenju et al. 2011) showed that rural and urban populations look to radio or newspapers, respectively, for their information. Although this is not a new concept, media outreach in Africa to date has largely been untimed (in terms of when the country and products are ready) and untargeted (to audiences and media that matter).

In addition, trust and experience are factors. For example, a study in the Philippines (ISAAA 2011) demonstrated that in mass media the use of metaphors—which play an important role in the construction of social and political realities and have to be used frequently to explain complex subjects—changed dramatically over time and experience. A common metaphor, fear, was used 51 percent of the time during the early years of the conversation in the Philippines. However, over 10 years the metaphors changed dramatically; the use of fear significantly decreased toward the second half of the decade, at the same time that products were being developed for the Philippines, in the Philippines, so they were relevant and familiar to the people. The study shows that the education of select media representatives is also important.

A Panos Institute analysis revealed that in those countries where media are closely aligned with the political institutions, government positions on biotechnology are mirrored in media coverage (Juma and Serageldin 2007). Developing a scientifically cognizant and independent media with an ability to evaluate and judge information and to formulate an opinion would be an important step to resolve the philosophical stalemate.

A number of initiatives have been implemented to inform the media, including "seeing is believing" tours and visits to biotech trial sites within Africa and elsewhere (Europe and the United States for media training sessions conducted by African scientists). Although such efforts have been effective, their impact has not been systematically measured, and a more comprehensive and strategic approach is needed. A number of recommendations by the African Biotechnology Stakeholders Forum (ABSF) with respect to the development of a media database are worth noting in this regard. A database would do the following:

- Establish a more detailed breakdown of target audiences in national, regional, and international public opinion research employing common methodology.
- Conduct internationally comparable systematic analysis of media coverage to identify technology presentation.
- Determine the level of public interest in science and its change over time.
- Assess the credibility of scientists in the news media and the general public in identifying national differences in opinion.
- Encourage two-way communications and be aware that concerns expressed in questions reflect public attitudes.
- Increase the biotechnology community's awareness of the importance of cooperating with the media.
- Improve understanding of how the media function on a daily basis, including their need to meet rigid deadlines.
- Sensitize scientists as to how they are perceived by the media.
- Encourage scientists to enroll in media training exercises.
- Encourage institutions to explore internships and other cross-fertilization programs between educational institutions and the media.

Developing Effective, Targeted Strategies

To avoid the misuse of valuable time, money, and goodwill on outreach efforts directed to the four groups addressed above, it is necessary to develop a targeted matrix approach. A new tool that creates influence and network maps has been particularly helpful in informing countries at various stages of the biotechnology debate—from policy development to broad-scale public outreach.

NetMapping, developed by IFPRI, is an interview-based mapping tool that helps participants understand, visualize, discuss, and improve situations in which many different entities influence the outcomes (Schiffer and Waale 2008). NetMapping helps stakeholders understand each other's goals, helps define the connections between disparate groups of stakeholders, and helps define a clear, prioritized picture of where resources are best invested to achieve a goal.

The approach has been used in Ethiopia, Indonesia, Kenya, Malawi, Nigeria, Uganda, and Vietnam to define effective strategies for communication, outreach, and political engagement, and it could be used more broadly in a continentwide effort to inform a biotechnology outreach strategy at high political and structural levels between and among African countries.

The Way Forward: Recommendations for Concrete Next Steps

In this analysis we have attempted to present a clear, comprehensive, and evidence-based situation analysis that delineates and dissects the possible role for biotechnology in Africa's agricultural development. The analysis presents a snapshot of the current situation; offers a realistic assessment of the continent's capacity to use, develop, and adopt the technology; and identifies a number of issues that must be addressed in order to move beyond the current level of controversy, which is persistent throughout the continent.

In developing this review we noted a number of clear gaps and needs that, with targeted and sustained efforts and resources, could be addressed to create a pathway for progress in demystifying the technology. Chief among these was the recognition that *accurate and recent data are seriously deficient* on many of the issues touched on in this report—capacity, financing, the economic impacts of various crops, scientific infrastructure, political understanding, and societal attitudes and perceptions. This presents an immediate problem for prioritizing action plans and resource allocations, because decisions made anytime soon will be based on an incomplete or possibly inaccurate delineation of the problems and opportunities at hand.

Based on this review, *inadequate funding of public agricultural research and development (R&D) on biotechnology and genetic modification (GM) technology and lack of capacity in regulatory systems to inform the decisionmaking process about biotechnology are paramount issues in Africa.* These issues need urgent attention, despite a number of initiatives that are under way. To enhance the availability of GM varieties suited to Africa, increased public investment in agricultural R&D for biotechnology, including the breeding of GM crops, is essential. To guarantee science-based regulation of new GM varieties, appropriate regulatory systems are needed. Only seven African countries currently have functional regulatory frameworks. (Ghana may soon be added to the list.) Biosafety initiatives such as those being undertaken by the Program for Biosafety Systems (PBS), which is managed by the International Food Policy Research Institute (IFPRI), as well as by the African Biosafety Network of Expertise (ABNE) and other organizations, are limited to a few countries and could benefit from increased coordination. Expanded efforts are needed to build practical, functioning frameworks in additional countries.

Related efforts are also needed to build capacity in agricultural stewardship and to continue the work initiated by the Forum for Agricultural Research in Africa Strengthening Capacity for Safe Biotechnology Management in Sub-Saharan Africa (FARA/SABIMA) project to maintain the efficacy of new varieties postdeployment. Coordination of efforts among service providers would be a desirable outcome as well, but this will require some level of consensus or standardization to alter the current mosaic of approaches and philosophies that is evident in regulatory frameworks throughout Africa. An impact assessment of regulatory approaches could inform an assessment of the various regulatory capacity-building efforts currently under way. Additional support is also needed for regulatory harmonization. To date, the most progressive example is from the Common Market for Eastern and Southern Africa (COMESA). Holding a workshop that highlights this approach for other regional economic communities (RECs) in Africa might be an initial step toward harmonization efforts in other regions.

As a primary step, this report highlights an immediate need to *further refine the in-country assessments presented here and to initiate an updated data collection exercise* using standardized and accepted methods of quantitative and qualitative reporting that disaggregate R&D capacity in biotechnology from the more general assessments of agriculture R&D typically pursued. IFPRI's Agriculture Science and Technology Indicators (ASTI) project could be an instrumental partner in this regard. (See www.ifpri.org/themes/asti.htm.) Based on these assessments, clear priorities to build capacity could be identified for those countries that have an interest. It is likely that this will initially require a targeted approach focused, perhaps, on a few countries that may have an adequate critical mass of human resources but may lack the policy and institutional frameworks required to fully drive progress in biotechnology research and development.

A related recommendation focuses on the need to *better engage the majority of African countries, which currently have little to no actual practical experience with this technology.* For most countries in Africa, the debate about biotechnology is largely an academic exercise, and policies, and as a result, tend to be established without the benefit of practical experience and practical considerations. As Table C.2 indicates, a significant number of products have been in the technology pipeline (many stemming directly from public-sector funding or from innovative public-private partnerships [PPPs]). The technical focus is on a wide variety of constraints and an ever-expanding target group of countries. An ex ante analysis of some of these prospective products in advance of their actual deployment could be useful to better inform the risk-benefit discussion about this technology in a way that will have greater meaning for more African countries. In addition, for many of these products in development, it will also be useful to develop a thoughtful assessment of the key challenges that may affect the commercialization or delivery pathway. This will be especially important for public-sector products.

However, much of the information shown in Table C.2 was the result of a data collection effort on public-sector GM crop research undertaken by IFPRI in 2003. More than 10 years later, little is known about the subsequent status of many of these projects. One effort that is important to mention is the online document developed by FARA that lists GM projects in Burkina Faso, Ghana, South Africa, Tanzania, and Uganda, among many other biotech indicators for these and other counties (FARA n.d.). The International Service for the Acquisition of Agri-biotech Applications (ISAAA) has published a different report with detailed information on GM projects in Africa (James 2012, 2013). What is lacking is a database of agricultural biotechnology that is centrally located and easily accessed; such a database will be critical to track progress and achievements on the continent. A "Lessons Learned" update of Table C.2, expanded to include new projects under development, will be critical to advance an understanding of the technical, social, structural, and policy issues that will drive the development process for biotech products. In addition, there are a number of other biotechnology opportunities on the horizon—for livestock, fisheries, and forestry, to highlight just a few examples. These may pose unanticipated issues and may require further study to understand specific impacts or constraints.

Related to the aforementioned recommendations about impact and capacity assessment is the need to fully analyze the role of women specifically in relation to biotechnology. The rationale here is obvious. Women farmers account for an overwhelming 70–80 percent of the labor force used for food production in Africa, yet the impacts of GM technology on women, specifically, have not been thoroughly evaluated—neither those of the GM crops already in commercial use nor those of products in the pipeline, many of which may directly affect women and children selectively. Current discussions about the impacts of GM crops on women, both good and bad, are largely anecdotal. Accurate, verifiable data are needed.

In addition, the role of women in the rhetorical debate about biotechnology is underappreciated and not in evidence, despite the increasing numbers of women in high-level political positions. Outreach to women and women's organizations has not been a priority; perception testing of women from all segments of society (from farmers to urban professionals to politicians) has not been systemically implemented; and women, as a collective voice, have not been heard in a way that is meaningful in establishing political and policy positions about biotechnology in Africa. A systematic initiative that provides a thorough, gender-specific impact assessment of biotechnology and an accompanying outreach effort would be beneficial to engage a majority of Africa's population, who are today largely sidelined. This initiative could include high-level outreach under the auspices of the African Union (AU), as a specific initiative for women parliamentarians, or at the ongoing negotiations of the Cartagena Protocol on Biosafety (CPB), to name just a few examples.

PPPs have been a useful means to access proprietary technologies (predominantly from the West) on behalf of pro-poor crops and constraints. However, the global situation with regard to biotechnology use and adoption is rapidly evolving, with greater levels of activity seen in emerging countries such as Argentina, Brazil, China, and India. These same countries are also at the center of a growing trade relationship with Africa and, as such, are likely to influence the debate about biotechnology on the continent. Efforts could be formulated to broaden the biotech dialogue beyond the EU and the United States by including these new partners in political or public outreach efforts. These partners offer interesting research possibilities for the development of additional agreements and PPPs and could provide needed technical and policy advice.

An enlightened discussion of intellectual property rights (IPR) and the various issues that are at the center of the IPR debate is also needed and is essential to any discussion about building biotechnology capacity (or innovation capacity in general). The various points of conflict need to be carefully dissected, with an array of options presented to address concerns and differing agendas. This dialogue needs a political and practitioner focus. IPR training for lawyers and technology transfer professionals is also needed. Proposed interventions could be in the form of workshops, small-group trainings, or train-the-trainer events, which have worked for other capacity-building efforts.

Finally, an effective strategic plan for outreach and communication is crucial to break the cycle of polarized rhetoric about GM technology in Africa. This approach needs to be sustained and stratified across all levels of society, and ideally it should start from a baseline assessment of current attitudes and perceptions. Such assessments do not exist in Africa; it is impossible to understand information gaps, the information needed, or the appropriate delivery routes for information in the absence of a baseline perception analysis. The use of innovative tools for social network analysis (such as IFPRI's NetMapping methodology) could be a useful starting point toward the development of an approach to outreach and communications. Because such efforts can be quite resource intensive, it is important to identify a strategy and an accompanying set of priorities before pursuing myriad tactics and activities (this latter approach has not been especially effective in Africa).

Appendix A: Select Country Summaries

Roshan S. Abdallah, Matthew Dore, Margaret Karembu, John Komen, Boniface Mkoko, Daniel Osei Ofosu, Theresa Sengooba, Idah Sithole-Niang, and David Wafula

The following pages represent summaries for a number of countries in Africa, with condensed information related to each country's (1) research capacity, (2) biotech pipeline, (3) biosafety capacity, and (4) political position (including outreach efforts, where known). Where sufficient information exists, tables have also been included. The selection of featured countries was subjective, based on our personal knowledge and that of others, to reflect those countries that have a critical mass of agricultural biotechnology (agbiotech) activity. We recognize that other countries not selected may have ongoing work and policies worth noting, but for the purposes of this report they have not been featured at this time. We believe that performing a thorough review of all countries with current data and information would be a useful exercise.

BURKINA FASO

Research Capacity

Over the past 10 years Burkina Faso has built its national capacity to regulate research and deliver genetically modified (GM) varieties. It has a limited but highly skilled corps of agbiotech researchers who have paved the way for the development of *Bacillus thuringiensis* (Bt) cotton for commercial production. Monsanto contributed resources to make this process possible, assisting the national research institute, the Institut National de l'Environnement et des Recherches Agricole (INERA), in transferring the Bt technology to two regional varieties, STAM 59 and STAM 103 (Vitale et al. 2010), making it possible for INERA to successfully implement the field trials up to commercialization.

Biotech Pipeline

About 4,500 farmers planted Bt cotton on 115,000 hectares of land in 2009 (James 2009). The adoption rate increased significantly in 2010 and beyond. About 150,000 farmers planted Bt cotton in 2013 on 474,000 hectares, four times more than in 2009 (James 2013). Vitale et al. (2010) document that the yields of adopters were, on average, 18.2 percent higher than those reported by conventional cotton farmers, and net profits increased by US$61.88 per hectare. The gains were realized primarily due to a reduction in the number of insecticide sprays required to control bollworms. Aside from the successful commercialization of cotton varieties, Burkina Faso has three other biotech-related projects in the pipeline (Table A.1). The first one is a multicountry cowpea research project led by the African Agricultural Technology Foundation (AATF) in partnership with INERA in Burkina Faso and with national research institutes in Ghana and Nigeria. The National Biosafety Authority (NBA) has approved field trials for Bt cowpeas. The second project is Africa Biofortified Sorghum (ABS) with Africa Harvest, which targets Burkina Faso, Kenya, and Nigeria. The third is the Nitrogen Use Efficient Water Use Efficient and Salt Tolerant (NEWEST) rice

TABLE A.1 Burkina Faso: Genetically modified crops in the pipeline, 2014

CROP	IMPORTANCE	TRAIT	STAGE	PARTNERS
Cotton	Income	Insect resistance and herbicide tolerance	Commercial release since 2008	Monsanto, Institut National de l'Environnement et des Recherches Agricole (INERA)
Cowpeas	Food	Insect resistance	Confined field trials (CFTs)	African Agricultural Technology Foundation (AATF), Network for the Genetic Improvement of Cowpea for Africa (NGICA), International Institute of Tropical Agriculture (IITA), Council for Scientific and Industrial Research (CSIR), Monsanto, INERA
Rice	Food	Nitrogen use efficiency, salt tolerance	Pre-CFTs	AATF, Cooperative Resources International (CRI), International Center for Tropical Agriculture (CIAT), Arcadia Biosciences
Sorghum	Food	Biofortification	CFTs	Africa Harvest, DuPont, Pioneer, INERA

Source: FARA (n.d.); updated by authors.

project, which targets, aside from Burkina Faso, Ghana, Nigeria, and Uganda. To develop this rice technology, in May 2012 AATF signed a license agreement with Japan Tobacco (JT) to use JT's transformation technology.

Biosafety Capacity

The Burkina Faso National Assembly passed the country's Biosafety Law in early 2006, establishing Burkina Faso as the first West African country to have enacted such a law. The bill established the NBA as the regulatory body, with members coming from several government agencies and nongovernmental organizations (NGOs). Although not established by the law, the NBA is led by and housed in the offices of the Ministry of Environment (Birner et al. 2007). In 2003, 2006, and 2007 the NBA approved what still constitutes the first field trials in the region; in 2008 it also approved the commercial release of the first GM crop in West Africa, culminating a process that took almost a decade of negotiations, planning, and capacity learning. An amendment of the Biosafety Law was promulgated in 2013 to give more political autonomy to the NBA but also with a view to introducing some strict liability provisions (USDA-FAS 2013).

Political Position

Burkina Faso has established itself as the leader in biotechnology in the West Africa region. With the solid organization and alliance among the Société Burkinabé des Fibers Textiles (SOFITEX), Faso Cotton, and the Société Cotonnière du Gourma (SOCOMA) from the industry side, along with INERA and the Union Nationale des Producteurs de Coton du Burkina (UNPCB), the country has demonstrated the capacity and the political will to implement GM crops.

EGYPT

Research Capacity

Egypt has one of the most advanced agbiotech sectors in Africa. Its Agricultural Research Council (ARC) has been actively researching and developing GM crops since it launched the Agricultural Genetic Engineering Research Institute (AGERI) in 1990. AGERI is located within the ARC, which falls under the Ministry of Agriculture and Land Reclamation (MALR) in Giza. This facilitates interface with other ARC institutes and provides a focal point for biology and genetic engineering for crop applications in Egypt. Other key biotech research institutions include the National Research Centre Agriculture Division and the faculties of agriculture at Cairo University, the University of Alexandria, and Ain Shams University.

Biotech Pipeline

AGERI is engaged in cutting-edge projects in the fields of virus, insect, fungus, and nematode resistance; stress tolerance; genome mapping; and biomolecular engineering. Ongoing trials involving GM crops include insect resistance in cotton; virus resistance in cucumbers, squash, melons, and muskmelons; potato leaf roll virus and potato virus Y (PVY) resistance in potatoes; tomato yellow leaf curl virus (TYLCV) resistance in tomatoes; zucchini yellow mosaic virus (ZYV) resistance in cantaloupes; sugar cane mosaic virus (SCMV) resistance in sugar cane; Lepidoptera resistance in maize; potato tuber moth (PTM) resistance in potatoes; and salt tolerance in wheat. In 2008 Egypt approved the cultivation and commercialization of Bt maize variety MON 810 (Table A.2.)

TABLE A.2 Egypt: Genetically modified crops in the pipeline, 2014

CROP	TRAIT	IMPORTANCE	INSTITUTIONS INVOLVED	STAGE
Maize	Insect resistance	Feed and incomes	Monsanto, Agricultural Genetic Engineering Research Institute (AGERI)	Approved for commercialization in 2008
	Insect resistance		Pioneer, AGERI	Confined field trials (CFTs)
Cotton	Insect resistance		Agricultural Research Council (ARC)	CFTs
Wheat	Drought tolerance		AGERI	CFTs
	Fungus resistance		AGERI	CFTs
	Salt tolerance		AGERI	CFTs
Potatoes	Virus resistance		AGERI	CFTs
Tomatoes	Virus resistance		AGERI	Contained greenhouse experiments

Source: Compiled by authors from Karembu, Nguthi, and Ismail (2009).

Biosafety Capacity

Egypt's national biosafety system was formally instituted by MALR through two ministerial decrees (nos. 85 and 136) issued in 1995. Procedures for commercializing transgenic crops (genetically modified organisms, or GMOs) were established in 1998 by Ministerial Decree 1648. The National Biosafety Committee is responsible for implementation of the biosafety system and for decisionmaking on approvals of GMOs.

Political Position

The country enjoys positive political support for agbiotech, particularly from the Ministry of Agriculture. The establishment of AGERI under the ARC was a strong reflection of the political will to support modern biotechnology. The decision to commercialize Bt maize in 2008 also demonstrated the confidence that government institutions have in the technology.

Egypt VISION-EBIC (Egypt Biotechnology Information Center), supported by ISAAA and hosted by AGERI, and the Open Forum on Agricultural Biotechnology (OFAB) are the main mechanisms for engaging the public and disseminating information on agbiotech.

ETHIOPIA

Research Capacity

The Ethiopian Agricultural Research Organization coordinates research and development on agbiotech nationally, monitors and evaluates such activities, and finances research projects. Other key institutions include the Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa University, the National Veterinary Institute, the National Animal Health Research Laboratory, the Institute of Biodiversity Conservation, the International Livestock Research Institute (ILRI), and the regional agricultural research institutes (ARIs).

Biotech Pipeline

Biotechnology R&D in Ethiopia is confined to tissue culture, molecular markers, biofertilizers, and biopesticides.

Biosafety Capacity

The Environmental Protection Authority is responsible for all types of authorization of GMOs. The country's legal framework is contained in the Biosafety Proclamation passed in 2009.

Political Position

Ethiopia's biosafety framework is precautionary and prohibitive. It poses a major hindrance to biotechnology R&D in the country. For instance, the legal framework demands that an advanced informed agreement be obtained before a living or dead modified organism (MO) may enter Ethiopia, and the same regulatory procedures apply for all uses of MOs (for instance, food or feed, contained use, confined filed trials, and environmental release, including that of pharmaceuticals).

GHANA

Research Capacity

Ghana has a well-established agricultural research infrastructure, with institutes located in the prime crop production centers across the country. This infrastructure is built around a network of 14 Council for Scientific and

TABLE A.3 Ghana: Genetically modified crops in the pipeline, 2014

CROP	TRAIT	IMPORTANCE	INSTITUTIONS INVOLVED	STAGE
Rice	Nitrogen use efficiency, salt tolerance, water efficiency	Food	Council for Scientific and Industrial Research (CSIR)–Kumasi, African Agricultural Technology Foundation (AATF)	Confined field trials (CFTs)
Cotton	Insect resistance	Income	CSIR–Savannah, Agricultural Research Institute, Monsanto	Multilocation trials
Cowpeas	Insect resistance	Food	CSIR–Savannah, Agricultural Research Institute, Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia), AATF	CFTs
Sweet potatoes	Nutritional improvement	Food	Tuskegee University (United States), CSIR–Kumasi	CFT approved

Source: FARA (n.d.); updated by authors.

Industrial Research (CSIR) research centers as well as the University of Ghana (Legon), the Kwame Nkrumah University of Science and Technology (Kumasi), and the Biotechnology and Nuclear Agriculture Research Institute (BNARI, Legon), under the Ghana Atomic Energy Commission. Highly trained and experienced professionals representing the various disciplines of traditional agricultural science as well as modern biotechnology can be found within this research network. A particularly strong complement of professional staff and facilities is focused on improving crops significant to the diet and the economy of Ghana, including cassava, cowpeas, maize, and rice.

Biotech Pipeline

Due to this quality research infrastructure and the diversity of its agriculture, Ghana is an attractive country in which to conduct R&D on crops improved via the tools of modern biotechnology. There are several active research collaborations under way between laboratories in Ghana and international scientists. These include (1) a joint effort between Tuskegee University (US) and CSIR-Kumasi focused on the nutritional improvement of sweet potatoes, (2) an insect-resistant cowpea effort between AATF (Nairobi) and CSIR's Savannah Agricultural Research Institute (SARI), (3) an improved rice project at CSIR-Kumasi with AATF as a partner, and (4) a collaboration between Monsanto and CSIR-SARI on insect-resistant cotton (Table A.3). In addition, the Donald Danforth Plant Science Center (US) is establishing a cassava collaboration with the University of Ghana and BNARI.

Biosafety Capacity

From 2004 to 2008, the PBS was actively engaged in biosafety capacity building in Ghana. This included holding workshops, seminars, and in-field training activities with staff from universities, CSIR institutes, BNARI, and regulatory agencies. The subject matter spanned the entire spectrum of biosafety issues as applied to GM crops, including conducting field trials, food and feed safety, and environmental risk assessments. This in-country biosafety capacity, further supported by successive UNEP-GEF biosafety capacity projects, is an additional attraction to outside collaborators to position their research efforts in Ghana.

Political Position

In 2008 a legislative instrument was put into place that provided the National Biosafety Committee with the authority to review and approve confined field trial (CFT) applications for GM crops. This action resulted in the initiation of CFT applications for GM cowpeas, rice, and sweet potatoes. More recently, in December 2011 the Ghanaian Parliament passed formal biosafety legislation to enable the granting of commercial approvals of GM crops. This will no doubt spur an increased interest in international partners to position their product development projects in Ghana.

KENYA

Research Capacity

Capacity for biotechnology R&D in Kenya has been strengthened gradually over the years. Biotechnology R&D work includes tissue culture applications, marker-assisted selection, genetic engineering, and work in other advanced fields such as genomics and bioinformatics. More than 100 scientists in public and private R&D institutions are engaged in advanced biotechnology R&D work. The Kenya Agricultural Research Institute (KARI) is the country's premier public research institution in biotechnology. KARI has established a center dedicated to biotechnology. It has a biosafety level 2 (BSL-2) greenhouse and several laboratories. Efforts to strengthen

TABLE A.4 Kenya: Genetically modified crops in the pipeline, 2014

CROP	TRAIT	IMPORTANCE	INSTITUTIONS AND DEVELOPMENT PARTNERS INVOLVED	STAGE
Maize	Insect resistance (Insect-Resistant Maize for Africa [IRMA] against stem borers)	Food and income	Kenya Agricultural Research Institute (KARI), International Maize and Wheat Improvement Center (CIMMYT), Monsanto, University of Ottawa, Syngenta Foundation for Sustainable Development	Confined field trials (CFTs)
	Drought tolerance (Water-Efficient Maize for Africa [WEMA])		African Agricultural Technology Foundation (AATF), CIMMYT, KARI, Monsanto, Bill and Melinda Gates Foundation (BMGF)–Howard G. Buffett Foundation	CFTs
Cotton	Insect resistance (bollworms)		KARI, Monsanto	CFTs completed
Cassava	Cassava mosaic disease resistance (BioCassava Plus)	Food, processing, and income	KARI, Danforth Plant Science Center, Donald Danforth Center	CFTs
	Enhanced levels of iron and zinc, protein, vitamins A and E	Food, health, and income	Donald Danforth Center, International Institute of Tropical Agriculture (IITA), International Center for Tropical Agriculture (CIAT)	
Sorghum	Biofortification with increased levels of iron, zinc, vitamins A and E	Food, health, and income	A consortium of nine institutions led by Africa Harvest Biotech Foundation International (Africa Harvest), Pioneer International, KARI	Contained greenhouse experiments concluded; CFTs application approved by National Biosafety Authority (NBA)
Sweet potatoes	Weevil resistance	Food and income	International Potato Center, Kenyatta University	CFTs

Sources: Karembu, Nguthi, and Ismail (2009); Karembu et al. (2012).

and expand the human resource base in biotechnology have been recognized. Currently all public universities in Kenya are offering BS and postgraduate degrees in biotechnology and biosafety. The universities have cutting-edge facilities and research programs. For instance, the University of Nairobi has the Center for Biotechnology and Bioinformatics (CEBIB), and Kenyatta University has a modern plant transformation facility and BSL-2 greenhouse. Kenya is also the domicile of the Biosciences eastern and central Africa (BecA) regional hub, which is located on the ILRI campus. BecA has state-of-the art facilities and laboratories for bioscience R&D in the areas of crops and livestock.

Biotech Pipeline

Kenya has been engaged in modern biotechnology R&D for about a decade. A number of GM crops are in the pipeline of development and deployment. These include maize, cassava, sorghum, and cotton. The main traits being tested at the CFT stage include insect and disease resistance, drought tolerance, and biofortification. GM cotton is approaching the commercialization phase (Table A.4). In the area of livestock biotechnology, recombinant livestock vaccines and diagnostic tests have been developed.

Biosafety Capacity

Kenya has made steps toward establishing a full-fledged, functional biosafety system. These efforts were initiated in 1998 through the support of the United Nations Environment Programme–Global Environment Facility (UNEP-GEF) to enable biosafety systems. The country's legal and policy frameworks and institutional arrangements for governing biotechnology include the national biotechnology development policy approved in 2006, the Biosafety Act enacted in 2009, the NBA created in 2010, and regulations on the contained use, environmental

TABLE A.5 Malawi: Genetically modified crops in the pipeline, 2014

CROP	TRAIT	IMPORTANCE	INSTITUTIONS INVOLVED	STAGE
Cotton	*Bacillus thuringiensis* (Bt, insect resistant)	Income generation	CSIR–Kumasi	Multilocation confined field trials
Cowpeas	Bt	Food security	Bunda College–African Agricultural Technology Foundation (AATF)	Preparation of Bt cowpea application

Source: Compiled by Boniface Mkoko.

release, import/export, and transit of agbiotech products published in 2011. Eight regulatory agencies are designated under the Biosafety Act to support the decision-making mandate of the NBA in various ways. Technical guidelines and manuals to enforce compliance with the procedures for conducting CFTs and meeting other biosafety requirements have been developed.

Political Position

The country has been able to embrace modern biotechnology because of a high degree of political will and commitment. Kenya was the first country globally to sign the Cartagena Protocol on Biosafety (CPB) in 2000. Former presidents have presided over several key functions, such as the opening of biotechnology and biosafety facilities at KARI and the BecA-LRI biosciences hub. The former prime minister also made positive statements in Parliament in support of modern biotechnology. In July 2011 the cabinet approved the importation of GM maize to mitigate the precarious food insecurity situation in Kenya.

The process of building awareness and support for biotechnology adoption in Kenya has involved several public awareness and participation mechanisms, including the African Biotechnology Stakeholders Forum (ABSF), the ISAAA, and the National Biotechnology Awareness Creation Strategy (BioAWARE) under the National Council for Science and Technology.

Despite these previous advances, in November 2012 a ban on imports of GM commodities was imposed, which has created uncertainty among different stakeholders despite the fact that this ban has not been formally gazetted.

MALAWI

Research Capacity

An assessment of the biotechnology R&D capacity of national public and private research institutions in Malawi showed that the challenges faced by these institutions are generic and mostly revolve around a lack of well-trained human resources and well-equipped laboratories. There are moderately equipped laboratories in agricultural institutions and universities that are capable of conducting R&D, but research work has been limited to the tissue culture of crops such as bananas and beans, with no ongoing research on transgenic crops. In the past few years, biotech research capacity in the country has been strengthened through the training of five PhD plant breeders with advanced skills in transformations, but they lack the necessary equipment and facilities to carry out their research. A training course in biotechnology has been introduced in two universities at the undergraduate level, with total admissions of 20 students per year.

Biotech Pipeline

At its August 2011 meeting, the National Biosafety Regulatory Committee (NBRC) approved an application by Bunda College of the University of Malawi to conduct the first-ever CFTs in Malawi. The seed for the cotton CFT was planted in January 2013, and the trial was duly completed in July 2013. Plans are currently being developed for multilocation trials in traditional growing areas. Besides cotton, there is a Bt cowpea application under preparation (Table A.5).

Biosafety Capacity

The Government of Malawi has put in place a functional biosafety regulatory system that is capable of regulating and managing the development of biotechnology. The Biosafety Act was passed in 2002. In 2007 Malawi fully implemented the Biosafety Act through the enactment of the Biosafety Regulations. The regulations established the NBRC and a biosafety registrar to process, review, and provide advice on applications for CFTs and general releases of GM crops. A National Biotechnology Biosafety Policy was approved in June 2008.

Currently the National Commission for Science and Technology (NCST), with assistance from PBS, is initiating training and capacity-building activities for regulators, trial managers, and inspectors related to CFTs, and it will support research and outreach initiatives to enhance the understanding of biotechnology and biosafety.

Political Position

The development of different regulatory frameworks and institutional structures for the implementation of biotechnology activities in the country is a clear indication of political will and the government's commitment to biotechnology. This is evidenced by the Malawi National Biotechnology and Biosafety Policy, approved by the cabinet in 2008, which clearly advocates the adoption of modern biotechnology as one of the tools to boost agricultural production. This position was reinforced by Joyce Banda, the president of Malawi, who made positive statements in support of modern biotechnology in her opening speech to Parliament on May 18, 2012. Malawi intends to strengthen capacity in its regulatory framework, perform research on new transgenic crops (beans, cassava, cowpeas, and maize), and conduct awareness programs.

MAURITIUS

Research Capacity

Biotechnology R&D in Mauritius is mainly undertaken by the Food and Agriculture Research Council (FARC), the Mauritius Sugar Industry Research Institute (MSIRI), and the University of Mauritius. Plant tissue culture laboratories in Mauritius include those at the University of Mauritius, for teaching and research purposes. Other institutes include the FARC tissue culture laboratory; the Barkly laboratory of the Ministry of Agriculture, Food Technology, and Natural Resources (MAFTNR); the biofactory of the Department of Biotechnology at MSIRI; and Micro Lab Ltd., a private commercial laboratory.

Biotech Pipeline

In 1996 research was initiated at MSIRI on the genetic transformation of sugarcane to produce herbicide Basta–resistant (BR) varieties. The first transgenic BR sugarcane varieties were produced in 1999 and have been evaluated under greenhouse conditions only. No commercial releases of the crops have been approved in Mauritius to date.

Biosafety Capacity

Mauritius has a legal and institutional framework for decisionmaking on GMOs. The Genetically Modified Organisms Bill (no. 44 of 2003) was passed into law in March 2004. The National Biosafety Committee (NBC) is responsible for risk assessment and decisionmaking on the approval or rejection of GMOs. The government is in the process of establishing the Mauritius Agricultural Biotechnology Institute (MABI). This will eventually replace the NBC.

Political Position

The country is committed to embracing modern biotechnology as a tool for socioeconomic development.

MOROCCO

Research Capacity

The research community in Morocco is fairly advanced and conversant with GM technology and its potential benefits. However, biotechnology in Morocco is politically sensitive due to the country's proximity to Europe and the volume of its European exports: in 2010, Morocco's export market was worth US$3,360 million, 60 percent of which was fruit and vegetable exports to the EU. Ironically, Morocco also trades with South America and the United States in commodities such as corn and soybeans that are most likely of GM origin.

Biotech Pipeline

The country's biotechnology research is focused on tissue culture, vaccine production, fermentation, and molecular markers.

Biosafety Capacity

Although a National Biosecurity Committee was formed in 2005, there is no law on biotechnology in Morocco. A draft law was sent to the Ministry of Agriculture in 2008 and is still under review. Meanwhile, a representative Morocco signed the CPB and ratified it on April 25, 2011. This ratification is seen as an opportunity to finally establish a functional regulatory framework in Morocco. Moroccan law also stipulates that international treaties to which Morocco is a signatory supersede national laws.

Political Position

The political will to introduce GM crops appears to exist, but it is very sensitive to the perceptions of key trading partners.

MOZAMBIQUE

Research Capacity

There is limited agricultural biotechnology research capacity in Mozambique. The Biotechnology Laboratory at the Instituto de Investigação Agrária de Moçambique (IIAM) was refurbished by the US Agency for International Development (USAID) in 2004. The laboratory still operates at limited capacity due to equipment and expertise constraints. Its activities are limited to research on virus-free cassava, Irish potatoes, bananas, and sweet potato planting materials. In February 2011 Eduardo Mondlane University launched a master's degree program in biotechnology aimed at addressing some of these constraints. This is a joint program launched by several departments, including Veterinary and Human Medicine, Biological Sciences, and Agriculture and Forestry. Perhaps the most promising avenue to explore in Mozambique is the further development of a range of products already in the pipeline and destined for Africa.

Biotech Pipeline

A GM drought-tolerant maize being developed under Water-Efficient Maize for Africa (WEMA) is the only GM product currently under development that is targeted to Mozambique. The CFT site has been completed but was washed away by floods prior to planting. The other crop being considered for CFTs is insect-resistant cotton (Bollgard II) from the Monsanto Company. To date, no research agreement has been signed between the applicant, the Cotton Research Institute, and the technology provider, Monsanto.

Biosafety Capacity

The Mozambican Regulations and Biosafety Law were gazetted in April 2007 and launched at a public ceremony that was organized by the National Biosafety Committee, known as the Inter-Institutional Biosafety Group (GIIBS), in October 2007. Since that time the decree has not been adequately translated into other languages; as a result, it remains largely unknown, particularly to the English-speaking stakeholders. In addition, a number of areas for improvement have emerged following its publication. Currently PBS is backstopping work with the African Biosafety Network of Expertise (ABNE), AATF, and GIIBS to assist in the revision of the decree to address issues relating to risk assessment and public participation. Public consultations regarding the regulations were held in leading agricultural zones in 2012, which is a ministerial requirement prior to their adoption.

Political Position

There is political will to promote agbiotech in Mozambique, as demonstrated by the passage of the Biosafety Law in 2007, together with the appointment of the GIIBS. In May 2011, this political will was further demonstrated by Dr. Venâncio Massingue, the minister of science and technology, who tasked a visiting team of experts to assist with the review of the decree. More recently this political will was further demonstrated by a visit of the ABNE AATF team, which met with the minister. A two-day workshop was also held and a series of follow-up actions was recommended, including soliciting final input from key ministries and having the final decree and implementing regulations submitted to the minister. Subsequent to this the minister will provide a legal opinion on the rationale for revision of the decree for consideration by the Council of Ministers. The final stage would be for the minister to convene a meeting of the Council of Ministers presided over by the president.

NIGERIA

Research Capacity

There is a moderate to high research capacity among Nigerian institutions. A well-structured public R&D organization exists in the primary fields of agriculture. There is an apex organization called the Agricultural Research Council of Nigeria that acts as an umbrella body under whose auspices there are currently 15 ARIs addressing a wide variety of crops, fish, and livestock, as well as issues pertinent to them. These are spread through the agro-ecological zones of Nigeria. Agricultural colleges operate under these research institutes. Infrastructural challenges persist in the form of unstable electricity, lack of availability of equipment (such as freezers), and poor maintenance of structures such as greenhouses.

Biotech Pipeline

Four technologies have received approval from the Nigerian government for CFTs. These are biofortified cassava modified to express heightened levels of beta-carotene for pro-vitamin A and cassava biofortified to increase the iron level. The other two crops are biofortified sorghum modified to increase the bioavailability of iron, zinc, protein, and vitamin A and insect-resistant cowpeas, as detailed in Table A.6.

Biosafety Capacity

Biosafety administration is a mandate of Nigeria's Federal Ministry of Environment. There is a small, dedicated force of trained staff in biosafety management who have received training from a variety of institutes and organizations in Australia, Europe, and the United Kingdom, including training in biosafety at the master's level from the International Centre for Genetic Engineering and Biotechnology (ICGEB). Over the years they have acquired wide exposure from hands-on training at institutions in the United States, including the Danforth Plant Science Center. The staff has participated in several short-term workshops and in a variety of

TABLE A.6 Nigeria: Genetically modified crops in the pipeline, 2014

CROP	IMPORTANCE	TRAIT	STAGE	PARTNERS
Cassava	Food, health, industrial purposes, cash crop	Increased level of beta-carotene (for provitamin A)	Confined field trials (CFTs), third season	Donald Danforth Plant Science Center (DDPSC), National Root Crops Research Institute (NRCRI)
	Food, health, industrial purposes, cash crop	Nutrition enhancement for increase in iron level	CFTs second season	DDPSC, NRCRI
Cowpeas	Food and income	Insect resistance	CFTs, third season	African Agricultural Technology Foundation (AATF), Network for the Genetic Improvement of Cowpea for Africa (NGICA), International Institute of Tropical Agriculture (IITA), Purdue University, Monsanto, Rockefeller Foundation, US Agency for International Development (USAID), Department for International Development (DFID), Council for Scientific and Industrial Research (CSIR), Institut National de l'Environnement et des Recherches Agricole (INERA), Kirkhouse Trust, Institute of Agricultural Research (IAR, Zaria, Nigeria)
Sorghum	Food, health	Bioavailability of iron, zinc, protein, vitamin A	CFTs	Africa Harvest Biotech Foundation International (Africa Harvest), Pioneer, CSIR, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), AATF, Forum for Agricultural Research in Africa (FARA), University of Pretoria, Agricultural Research Council (ARC), University of California–Berkeley (UCB), IAR

Source: Karembu, Nguthi, and Ismail (2009); updated by Matthew Dore.

programs under the auspices of the CPB and its working sessions. Study tours to a variety of institutions in the United States have also added value to their knowledge. At the national level, there are more than 1,000 PhDs and MSs in specialist areas of biotechnology. This is a huge pool of human resources that can be easily retrained and given orientation for biosafety purposes. They are within the various government public institutions related to the environment, ARIs, and universities. A variety of partnerships have been negotiated with reputable organizations that have sent representatives to Nigeria to hold specialized training workshops on issues that must be addressed to ensure that local capacity is built across several public agencies, including those primarily charged with biosafety, phytosanitary, and food safety mandates. The lead partners in this regard include IFPRI/PBS, ABNE, AATF, and the Donald Danforth Plant Science Center.

Political Position

The political will to use biotechnology as a tool for national development was expressed strongly in Nigeria during the 1999–2003 presidency of General Olusegun Obasanjo. However, this did not translate into sustained funding, thus stifling growth in the sector. The issue of biosafety has remained on the back burner due to a lack of familiarity with the subject among successive actors of the political elite who are in a position to move things forward. Two other important factors that restrained political goodwill were the facts that public institutions with mandates for promoting biotechnology are fairly young and that the generally bad press associated with biotechnology, driven by interest groups with external backing, had made public figures lukewarm to agbiotech. All this is gradually changing due to the recent engagement of some development partners. Champions have arisen in the legislature and the public R&D sector who have provided open platforms for discourse. The passage of the Biosafety Bill in the Senate and the House of Representatives is a testament to the progress that has been made in recent times. With the advent of technocrats in the cabinet and the appointment of distinguished academics to provide leadership in the Ministries of Science and Technology and Agriculture, visible changes have become apparent and the political will to move forward with agbiotech has greatly increased. The political elite are now openly committing to the use of biotechnology to improve livelihoods and create jobs and are clamoring for presidential assent to the Biosafety Bill. What is left is for the president to clear all doubts on the subject of biosafety and to muster the political will to assent to the bill.

SOUTH AFRICA

Research Capacity

The South African biotechnology sector is small compared to the biotech sectors of international leaders, but it has a significant pipeline of innovations. The sector is characterized by a robust experience with first-generation biotechnology applications, advanced research institutes, and an enabling policy climate to support the development and expansion of the sector.

The 2003 National Biotech Survey identified 106 core and noncore companies, 622 research groups, and 911 research projects in the biotech sector (Mulder 2004). These companies, mostly private, employed 1,020 in staff-related biotechnology activities with a total turnover of over 300 million rand (US$37 million at today's exchange rate). The survey identified 154 projects and services with revenue of over 388 million rand (US$47.7 million at today's exchange rate). Of these 154 projects, 18 percent correspond to plants.

This survey showed that the majority of the core biotechnology companies were located in Gauteng (41 percent), Western Cape (37 percent), and Kwazulu Natal (15 percent) provinces. These companies had projects that focused mainly on plant biotechnology, followed by human health and industrial biotechnology (Mulder 2004). The majority of the noncore biotechnology companies were also located in Gauteng and Western Cape provinces, with a majority of the focus on plant applications (26 percent of the total).

Biotech Pipeline

South Africa has been growing, consuming, and trading in GMOs since 1997, when the first GM crop (cotton) was approved for commercialization. It is one of the countries in the world with accumulated evidence of the benefits of GM crops. Currently the country has commercialized GM maize (white and yellow), GM soybeans, and GM cotton. The benefits associated with the adoption of GM crops include increased yields, farm income gains, and reduced dependence and expenditure on crop protection chemicals. A significant number of crops are under development (Table A.7). Various papers and studies have shown that institutional factors in South Africa have limited the benefits of biotechnology applications, especially in cotton. The experience with cotton in South Africa points to the need to better understand the broad picture of technology adoption, product deployment, and stewardship in developing countries.

Biosafety Capacity

In 1997 South Africa enacted a GMO act that was amended in 2006. The legislation places emphasis on science-based risk assessment in decisionmaking. The country's success story in biotechnology is largely attributed to an enabling policy environment and a national biotechnology strategy that supports and stimulates innovations (FARA 2011). The commercial sector has recently expressed some concern about a changing biosafety climate that is becoming less science based and more precautionary. There is also concern that the system is too cumbersome and lacks adequate regulatory capacity and resources, resulting in more support for large multinationals than for indigenous organizations (Cooke and Downie 2010).

South Africa has also been a strong supporter of enabling regulatory systems in international forums, such as the CPB process. Socioeconomic considerations regarding commercial releases have been a part of the GMO act since its inception. Recently the Bt potato product was rejected, in part as a result of a socioeconomic analysis with respect to this product and also as a result of strong objections on the part of Potato SA. Labeling is also covered under two legislative instruments: a food safety provision under the Department of Health (2002) and a "consumer's right to know" provision under the Department of Trade and Industry (2011). Implementation of the latter is proving difficult. As a result, this provision is under review.

Political Position

The government of South Africa had initiated a program that supported the establishment of biotech regional innovation centers (BRICs) under the Department of Science and Technology to drive the growth and advancement of biotech platforms, with an initial commitment of US$75 million (Cloete, Nel, and Theron 2006) as evidence of its political commitment. In 2008 an act of Parliament resulted in the formation of the Technology Innovation Agency (TIA) (www.tia.org.za), which effectively merged the seven smaller BRIC agencies into one entity to support the commercialization of locally developed R&D. The TIA's mandate is broader than biotechnology and includes the commercialization of technologies in the areas of health, agriculture, energy, manufacturing, and information and communication technologies.

TABLE A.7 South Africa: Genetically modified crops approved and in the pipeline, 2014

COMMERCIALIZED CROPS			
Crop[a]	Trait[a]	Release into the environment	Approved for food and/or feed
Canola	HT		2001
Canola	HT		2001
Canola	HT		2001
Canola	HT		2001
Soybeans	HT		2001
Soybeans	HT	2001	2001
Cotton	IR	2003	2003
Cotton	HT/IR	2005	2005
Cotton	HT	2000	2000
Cotton	HT/IR	2007	2007
Cotton	IR	1997	1997
Cotton	HT	2007	2007
Maize	IR		2001
Maize	HT/IR	2003	2002
Maize	HT		2002
Maize	HT/IR		2003
Maize	IR	1997	1997
Maize	HT	2002	2002
Maize	HT/IR	2007	2004
Maize	HT		2001
Maize	HT/IR		2002
CROPS UNDER DEVELOPMENT			
Crop[b]	Trait[b]	Regulatory status	Partners
Soybeans	AP	CFT approved	—
Cotton	HT/IR	CFT	—
Maize	AP	CFT	—
Maize	AP–drought tolerant	CFT	African Agricultural Technology Foundation (AATF); Monsanto
Maize	HT/IR	CFT	—
Maize	IR	CFT	University of Cape Town, Pannar Seed Company
Sugarcane	VR and AP	Ready for commercialization	—
Potatoes	IR		Agricultural Research Council (South Africa) (ARC–South Africa), Michigan State University
Cassava	AP	CFT completed	—
Sorghum	NE	Greenhouse	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), University of Pretoria, Kenya Agricultural Research Institute (KARI), ARC–South Africa, Burkina Faso Environmental and Agricultural Research Institute (INERA), and Institute of Agricultural Research (IAR) in Nigeria

[a]CERA (2014).

[b]Compiled by authors from James (2013).

Notes: AP = agronomic property; CFT = confined field trial; HT = herbicide tolerance; IR = insect resistance; NE = nutritional enhancement; VR = virus resistance. Dash = data not available.

TANZANIA

Research Capacity

Tanzania has a modest but growing research capacity in biotechnology. Around 48 scientists are involved in agbiotech R&D. PhD holders represent 42 percent of the total scientists, with 46 percent at the master's level and the remaining 12 percent having received BS degrees. The ARIs that have human and infrastructural capacity for biotechnology R&D are ARI Mikocheni, ARI Uyole, Horti Tengeru, ARI Ukiriguru, and ARI Mlingano. ARI Mikocheni has well-established capacity, with facilities for tissue culture and micropropagation, plant disease diagnosis, DNA fingerprinting, and molecular marker–assisted selection. ARI Uyole, Horti Tengeru, and ARI Mlingano have acquired adequate facilities for tissue culture applications. Universities involved in agricultural biotechnology R&D are Sokoine University of Agriculture (SUA) and the University of Dar es Salaam (Department of Botany). SUA has laboratories for tissue culture and micropropagation, microbiology, molecular biology, immunology, pathology, biochemistry, and biotechnology research. It has also established a state-of-the-art seed pathology laboratory and the Genome Sciences Centre for research in functional genomics and bioinformatics. The Department of Botany at the University of Dar es Salaam has a small tissue culture laboratory and a molecular laboratory. Other biotech institutions include the Central Veterinary Laboratory (CVL), which has the national mandate to conduct research on animal diseases.

Biotech Pipeline

Tissue culture applications dominate biotechnology R&D in Tanzania. Work on genetic modification is still in its infancy in the country. In 2003, CFTs of GM tobacco free of nicotine were conducted in the country by US-based Vector Tobacco. The trials were terminated prematurely the same year due to the lack of a biosafety framework. Currently an application to test the drought-tolerant WEMA under CFTs is pending approval by biosafety authorities in Tanzania.

Biosafety Capacity

Remarkable steps have been taken to put in place key components of a biosafety regulatory system. The Division of Environment in the vice president's office is the national biosafety focal point. Other regulatory institutions include the Tanzania Commission for Science and Technology (COSTECH), the National Biotechnology Advisory Committee, the Tropical Pesticides Research Institute, and the Agricultural Biosafety Scientific Advisory Committee.

The legal framework for addressing biosafety issues is embedded in the Environment Management Act of 2004. Biosafety implementing regulations were published in 2009.

Political Position

A strong political will to promote agbiotech exists in Tanzania, as evidenced by the National Biotechnology Development Policy. The mission of the policy is to "create infrastructure for research, development and commercialization in biotechnology so as to ensure a steady flow of bio-products, bioprocesses and new biotechnologies for social and economic development of Tanzania" (Tanzania 2010, 3). However, the country's legal framework is prohibitive. Strict liability and redress provisions in the law and regulations are currently a hindrance to advancing biotechnology R&D in the country. Awareness is created through COSTECH and the Open Forum on Agricultural Biotechnology.

UGANDA

Research Capacity

Research capacity has been built in Uganda in both human resources and infrastructure in the past 15 years, mainly in public institutions, with the National Agricultural Research Organisation (NARO) hosting two advanced laboratories and more than 10 moderately equipped facilities. In addition, there are three private laboratories with R&D capacity for biotech, which are already commercializing tissue cultures in bananas, coffee, sweet potatoes, and pineapples. One public university also hosts an advanced agbiotech laboratory. The current biotech institutions would benefit from strengthening in key areas, such as improved governance and management, streamlined procurement of laboratory supplies, and reliability in amenities (electricity and water). Human resource capacity has been tremendously strengthened in the past 10 years, with more than 20 PhDs and 50 MS-level trained scientists with sufficient knowledge and skills to conduct biotech R&D in the existing facilities. Three public universities have now established biotechnology training programs at the undergraduate level, and more than 100 students have so far graduated from these programs. The major biotech tools applied in the country include tissue culture, disease diagnostics, genetic engineering, marker-assisted selection, vaccine production, gene discovery, and gene characterization.

Biotech Pipeline

Research is ongoing for seven crops of key importance for food and income security in the country, including

TABLE A.8 Uganda: Genetically modified crops in the pipeline, 2014

CROP	IMPORTANCE	TRAIT	STAGE	PARTNERS
Maize	Food and income	Drought tolerance	Confined field trials (CFTs), third season	National Agricultural Research Organisation (NARO), African Agricultural Technology Foundation (AATF)
		Insect resistance	CFT application submitted	NARO, AATF, Monsanto
Bananas	Food	Bacterial wilt resistance	CFTs, third season	NARO, AATF, International Institute of Tropical Agriculture (IITA)
		Nutrition enhancement (Fe and provitamin A)	CFTs, third season	NARO, Queensland University of Technology (QUT)
	Nematode resistance	CFTs	NARO, University of Leeds	
Cassava	Food	Virus resistance	CFTs	NARO, Donald Danforth Plant Science Center (DDPSC), IITA
		Brown streak virus resistance	Multilocation trials	NARO, DDPSC, IITA
Cotton	Income	Bollworm resistance and herbicide tolerance	CFTs completed	NARO, Monsanto
Sweet potatoes	Food	Sweet potato weevil resistance	Contained greenhouse trials	NARO, International Potato Center (CIP)
		Virus resistance	CFT application submitted to National Biosafety Committee (NBC)	NARO, CIP
Rice	Food and income	Nitrogen Use Efficient, Water Use Efficient, and Salt Tolerant (NEWEST) rice	CFTs, first season	NARO, AATF

Source: David Wafula and Theresa Sengooba; James (2012).

cassava, bananas, maize, and sweet potatoes. Tissue culture technologies have been commercially applied to bananas, coffee, and sweet potatoes, whereas genetic engineering technologies are under field testing in all crops mentioned above except for sweet potatoes, which are still in containment (Table A.8).

Biosafety Capacity

The development of a biosafety framework for Uganda was initiated 14 years ago with the assistance of the UN Environment Programme–Global Environment Facility (UNEP-GEF, 1997–2005). A focal point for the CPB was established in the Ministry of Environment and a competent authority at the Uganda National Council for Science and Technology. The drafting of the biosafety policy and the accompanying bill was initiated during this period. The country has also developed general guidelines for the application of GM technologies and has an active NBC. Further progress has been made during the past seven years with support from the Program for Biosafety Systems project, which has strengthened the capacity of the NBC and the IBCs in the evaluation of applications for field trials of GM plants and in making science-based decisions. Scientists have been trained in addressing biosafety concerns in research. Biosafety inspectors for GM field trials have also been trained in assessing the trials and monitoring them for regulatory compliance. Several manuals to guide field research with GM crops have been developed and are used to ensure compliance with biosafety principles during biotech R&D activities.

Political Position

Uganda has demonstrated political will in support of biotechnology. Yoweri Museveni, the president of Uganda, opened the National Biotechnology Centre at Kawanda in 2003 and proclaimed his support for biotechnology provided that safety concerns were taken into consideration. The government policy on biotechnology and biosafety was endorsed by the country's cabinet in April 2008. The principles of the Biosafety Bill have recently been approved by the cabinet, and the attorney general has been instructed to draft the bill. Though the Biosafety Bill is yet to be debated by Parliament, the progress being made in research involving GM crops and the established regulatory capacity are clear indications that Uganda is prepared to use modern biotechnology.

ZAMBIA

Research Capacity

The National Biotechnology Laboratory was commissioned in April 2007 at the National Institute for Scientific and Industrial Research (NISIR) to serve as a national reference laboratory. NISIR has a fully functional tissue culture laboratory for the development of disease-free crops such as bananas and cassava. The University of Zambia is undertaking biotechnology R&D work in Zambia. The university has been involved in tissue culture plant biotechnology for more than 10 years, focusing on induced mutation techniques for cassava improvement. It has had a functioning tissue culture laboratory for training and research since the mid-1990s. The university offers both graduate and undergraduate plant breeding courses. Its School of Veterinary Medicine also has facilities for the diagnosis and characterization of parasites such as trypanosomes and helminthes using molecular tools. Other institutions are also in the process of establishing biotechnology laboratories: (1) the Seed Control and Certification Institute for the characterization and genotyping of seed varieties, (2) the Central Veterinary Research Institute for the diagnosis and characterization of pathogens, and (3) the University of Zambia and NISIR laboratories for the characterization and genotyping of livestock.

Biotech Pipeline

Aside from the ongoing work on tissue culture, there are no biotechnology projects in Zambia. No GM crop has been introduced or approved for research trials. However, stakeholders in the cotton industry have demonstrated their interest in introducing GM cotton and implementing CFTs.

Biosafety Capacity

Zambia approved a national biotechnology and biosafety policy in 2003, which was followed by the enactment of its Biosafety Act in 2007. The scope of the Biosafety Act applies to the import, development, export, research, transit, contained use, release, or placing on the market of any GMO, whether intended for release into the environment; for use as a pharmaceutical; or for food or feed for processing (FFO), as well as any product of a GMO. Several regulations have been developed to operationalize the act, but these are currently under consideration by the Ministry of Justice. The National Biosafety Authority is not currently functional. It is relying on the National Biotechnology Laboratory under the National Institute for Scientific and Industrial Research as a reference laboratory for the detection and identification of GMOs. Monitoring capacity is also being developed at "points of entry" (the Seed Control and Certification Institute) as well as at the Zambia Agriculture Research Institute. Capacity-building support for risk assessment and risk management has been provided by the Norwegian Institute of Gene Ecology and China's Nanjing Institute of Environment Sciences.

Political Position

A representative of Zambia signed the CPB on June 11, 1992, and ratified it on May 28, 1993. In 2001/2002 the country experienced drought conditions that led to food deficits. A highly publicized rejection of GM food aid (maize) thrust the country into the midst of the political debate about the role of GM agriculture in Africa. At the time the Zambian government invoked the precautionary principle in rejecting GM food aid shipments because it did not have a legal and regulatory framework or appropriate capacity in place to oversee and regulate the shipment. The regulatory system is precautionary and excessively stringent. Article 19.1 of the 2007 Biosafety Bill states that the competent authority "shall not grant any approval for the importation, development, production, and release into the environment or placing on the market of any genetically modified organism or product of a genetically modified organism relating to any crop or livestock of strategic importance to national food security" (Zambia 2007, 155).

ZIMBABWE

Research Capacity

Progress in the Zimbabwean agbiotech arena slowed during the past decade as the economic situation in the country changed and the significant gains that had been made were lost. However, there are a few foci of biotech activity that could easily get back on track if funding were made available. Meanwhile, some of the activity around crops

TABLE A.9 Zimbabwe: Genetically modified crops in the pipeline, 2014

CROP	IMPORTANCE	TRAIT	STAGE	PARTNERS
Maize	Food	Drought tolerance	—	African Agricultural Technology Foundation (AATF), International Maize and Wheat Improvement Center (CIMMYT), Instituto de Investigação Agrária de Moçambique (IIAM), Monsanto
	Food	Nitrogen use efficiency	—	Improved Maize for African Soils (IMAS), Pioneer, KARI, Agricultural Research Council (ARC)
Maize	Food	Insect resistance	Laboratory	Agbiotech
Cotton	Income	Insect resistance, herbicide tolerance	Confined field trials	
Cassava	Food	Virus resistance	Laboratory	Agbiotech, Swiss Federal Institute of Technology
Brassicas	Food	Aphid resistance	Laboratory	Agbiotech
Irish potatoes	Food	Late blight	Laboratory	Agbiotech
Sweet potatoes	Food	Virus resistance	Laboratory	Agbiotech

Source: Compiled by Idah Sithole-Niang.
Note: Dash = data not available.

such as sweet potatoes, brassicas, Irish potatoes, and cassava could benefit from capacity strengthening with the conduct of CFTs.

Biotech Pipeline

Currently Zimbabwe has limited R&D activity because its researchers have no funding. Nevertheless, the country has a number of GM crops that have been under study, as detailed in Table A.9.

Biosafety Capacity

The first Biosafety Law was enacted in 1999 and passed as Statutory Instrument (SI) 20/2000. This law was pivotal in setting up the Biosafety Board, which then approved the very first set of CFTs for both Bt maize and Bt cotton in 2001. Both trials were conducted over three seasons during which data were collected. The technology performed very well, although no commercialization applications were received. It was during this time that the country experienced an economic downturn, with the result that some technology providers actually left the country. News of the possibility of another insect-resistant cotton undergoing CFTs in 2011 never materialized, because the approval given by the NBA was overruled by the minister of agriculture, who then declared a moratorium on GMOs in the country. Following the passage of SI 20/2000, the Zimbabwean Biosafety Law was streamlined to conform to the CPB, resulting in the National Biotechnology Authority Act of 2006. Furthermore, this law has seen the establishment of the National Biotechnology Authority, and the Biotechnology Policy is being developed. Alongside these efforts, the Second Policy for Science, Technology, and Innovation (STI) has been published and is currently in use.

Political Position

This Second Policy for STI, of which the former head of the Ministry of Science and Technology Development (MSTD) was the chief proponent, embraces biotechnology, genomics, and nanotechnology. There remain, however, strong anti-GM sentiments in the press and in other parts of the government. Although the Biosafety Law has been supported by the MSTD, there are dissenting voices emanating from the Ministry of Agriculture, reiterating rhetoric that has long since been abandoned elsewhere.

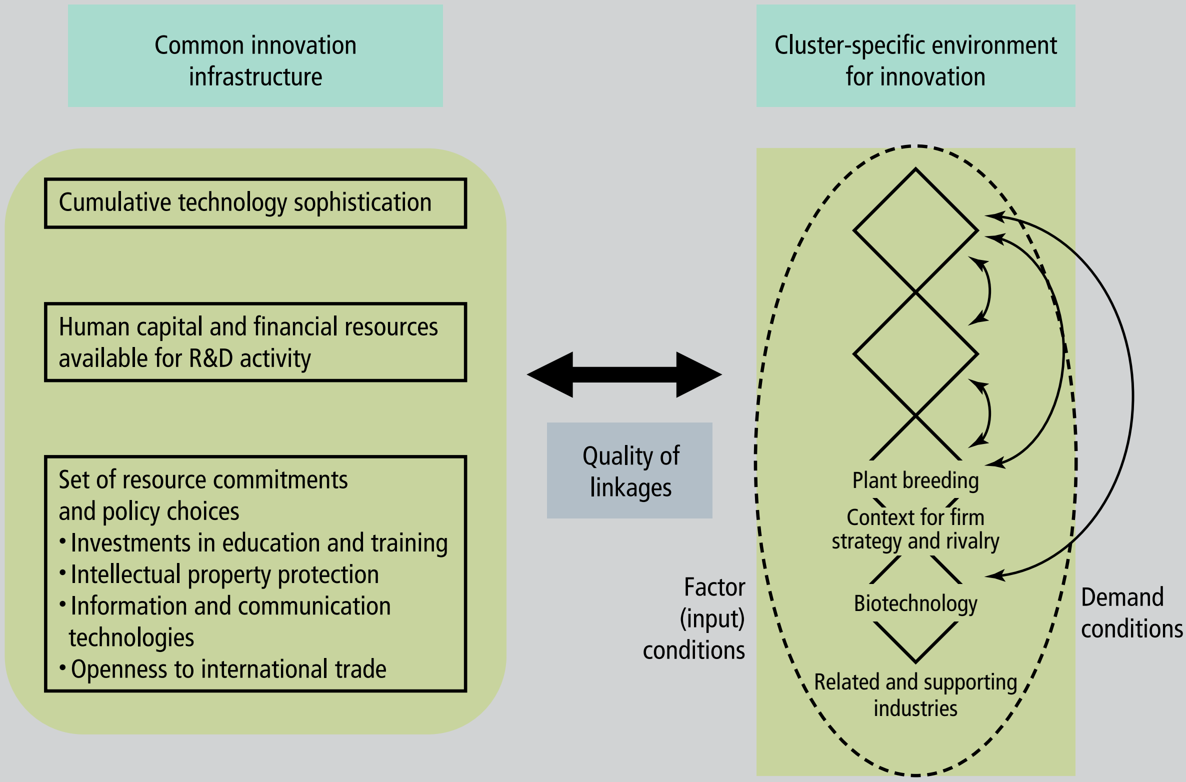
Appendix B: Rapid Assessment of National Biotech Innovative Capacity in Africa

In this appendix we briefly describe an application of the model to analyze the determinants of innovation proposed by Furman, Porter, and Stern (FPS 2002). Here we pursue a simplification of the FPS approach, which is similar to the ones suggested by Fuglie and Pray (2000) and Trigo (2003), in order to take a qualitative view of biotechnology capacity in general and of the factors that support research and development (R&D) in Africa. Not surprisingly, countries with a higher level of innovation tend to have more advanced biotechnology innovation systems.

The FPS conceptual framework considers two distinct levels of innovation and their linkages (Figure B.1). At an aggregate (national) level, the FPS model considers those determinants of innovation that are common to all innovative activities that are included under the "common innovation infrastructure." The common innovation infrastructure is the foundation of a nation's ability to support innovative activities and in some cases even enable new ones. Certainly there is a possibility for specific groups or firms in a country to innovate without the existence of a common national innovation infrastructure. However, long-term national capacity to create innovations in a broader spectrum of disciplines is hindered significantly by the absence of the common innovation infrastructure. A question arises as to the minimum common innovation infrastructure needed to support group-specific (that is, plant breeding and biotechnology) innovation. Although the answer to this question will vary from country to country, it is critical to view the system as a whole first and then to examine what will affect innovation at the group-specific level.

Innovation occurs in specific groups conducting research. These groups, named clusters by Furman, Porter, and Stern (and other authors), are the basic units of innovative capacity and may be groups of researchers, institutes, firms, or consortiums of research teams. Each individual cluster is connected to other related clusters interacting to support innovative capacity. Each individual cluster (or group of clusters) is subjected to its own set of factor (input) and output demand conditions, as well as a firm-specific context for strategy and rivalry. At the same time each cluster is closely tied to activities performed by related and supporting industries. This is a very dynamic process whereby opportunities and ideas arise depending on the strength of the innovative system.

FIGURE B.1 **The Furman, Porter, and Stern (FPS) model for determinants of national innovative capacity**



Source: Compiled by authors from Furman, Porter, and Stern (2002).

Although Figure B.1 has plant breeding and biotechnology as two distinct clusters, these two clusters overlap quite significantly, and they may be combined into one cluster that may be thought of as a *crop improvement cluster.* Note that the "cluster-specific environment for innovation" resides within the common innovative structure, and thus the quality of the linkages between those two levels of innovation (and between clusters) becomes critical in determining national innovative capacity. In many empirical studies these linkages have proved to be as critical to the innovation process as the internal cluster factors.

The components of the national innovative capacity framework described above are complex in nature but may be described somewhat qualitatively by using specific quantitative variables. Obtaining a dataset that is complete and covers a long enough time series to allow for the development of a quantitative FPS national innovative capacity framework is a complex task that goes beyond the scope of this report. A workable alternative is to use a subset of these frameworks, as we do below, or to perform a qualitative analysis. The critical task is to find alternatives to describe the common national infrastructure for innovation, cluster-specific data, and the linkages between levels and components.

METHODOLOGY

Step 1. Estimating Capacity Indicators

The following types of compiled data will enable us to provide a snapshot of the current situation in Africa with regard to biotechnology and innovation. We assessed different aspects of 56 countries in Africa using secondary data collected from the World Bank Development Indicators 2008, FAOStat, the Global Plant Breeding Initiative (GPBI) database, Transparency International, and other sources of data. Other potential indicators of innovative capacity may be used; unfortunately, there may be too many gaps in the information available for it to be usable without further data collection. Furthermore, there is a need to conduct in-depth studies examining organization-specific data that more accurately reflects existing innovative capacity in a country.

The capacity indicators we are looking for (in italics) and the types of data we can use to determine them (bulleted) are as follows:

Overall innovative capacity

- Scientific and technical journal articles (average)
- Scientific and technical journal articles (sum 1990–2005)
- Personal computers
- Public spending on education, total (percentage of gross domestic product [GDP])

Economy-wide status

- GDP per capita (constant 2000 US$)
- GDP per capita growth (annual percentage)
- GDP per capita, PPP (constant 2005 international $)
- Industry, value added (percentage of GDP)
- Industry, value added (percentage of annual growth)
- Agriculture, value added (percentage of GDP)
- Agriculture, value added (percentage of annual growth)
- Agriculture, value added (millions, constant 2000 US$)

Intellectual property situation

- Number of patent applications, nonresidents (1987–2005, total, World Bank 2011)
- Number of patent applications, residents (1987–2005, total, World Bank 2011)
- Total number of patent applications (1987–2005, total, calculated)
- Patent applications per million inhabitants (estimated by calculation)
- Corruption Perception Index rank (Transparency International)
- Corruption Perception Index 2010 (Transparency International)

Market size

- Land area (1,000 hectares, FAOStat, average 2000–2008)
- Arable land (percentage of total, FAOStat, average calculated from land and arable land)
- Arable land (1,000 hectares, FAOStat, average 2000–2008)
- Crop production index (average 1997–2004, 1999–2001 = 100, World Bank 2011)
- Population, millions (average 1997–2006, World Bank 2011)
- Population growth rates, percentage (average 1997–2006, World Bank 2011)
- Aggregate value of agriculture (percentage of GDP 1997–2006, World Bank 2011)

Strength of private sector

- Domestic credit provided by banking sector (percentage of GDP, average 1996–2006, World Bank 2011)
- Domestic credit to private sector (percentage of GDP, average 1996–2006, World Bank 2011)
- Ease-of-doing-business index (ranking: 1 = most business-friendly regulations, average 2005–2007, World Bank 2011)
- Business disclosure index (0 = less disclosure to 10 = more disclosure, average 2005–2007, World Bank 2011)
- Cost of business start-up procedures (percentage of gross national income per capita, average 2003–2007), World Bank 2011)
- Time required to enforce a contract (days, average 2002–2007, World Bank 2011)

Biotech capacity

We used a qualitative measurement based on our own experience with the region and classified countries based on whether they were

- Nonselective biotechnology importers
- Selective biotechnology importers
- Biotechnology tool users
- Biotechnology innovators

TABLE B.1 Policy situations to improve the use of biotechnology in Africa

POLICY SITUATION	DESCRIPTION
Nonselective biotechnology importers	• Countries have no accumulated institutional capacity. • Diffusion of new technologies (conventional or biotech) occurs spontaneously or through individual initiatives, without any supporting institutional framework.
Selective biotechnology importers	• Countries have an agricultural research infrastructure. • There are some local capacities for plant or animal improvement while new varieties are introduced through local importation and adaptive testing. • Mostly with external donor support, these countries have initiated the process of developing capacity in the biotech area through the incorporation of conventional biotechnology techniques (for example, tissue culture), capacity-building programs dedicated to human resources, and even activities for tending to the implementation of a national strategy for the development of the biotech sector. • Countries have regulatory frameworks in the areas of biosafety and intellectual property but lack experience in their implementation.
Biotechnology tool users	• There are established institutions and consolidated plant or animal improvement systems, which have a more or less constant rate of deployment of new varieties developed internally and use biotech tools in their activities. • Broader-spectrum tools from tissue and cellular cultures are used to marker assisted selection and even some genetic transformation, usually related more to commercial cash and/or export crops, which have a defined technological support system of their own. • National research systems have a high capacity, but it is not evenly developed across the components. • Countries may have some experience in the management of genetically modified organisms, even at the level of deliberate release.
Biotechnology innovators	• Countries have research and development systems with broad coverage from basic research (development of new techniques) to the development of specific products for a broad set of crops and species. • There are science and technology systems that can develop frontier science and have well-defined interaction channels with the productive sectors of the economy in order to maintain continuous links with the input and output markets. • Generally these systems also demonstrate established links with centers of excellence and advanced research centers in developed countries, which frequently materialize through joint research projects.

Source: Trigo (2003).

Biosafety capacity

We used a qualitative measurement based on our own experience with the region and classified countries depending on whether they have achieved the following biosafety milestones:

- Have completed National Biosafety Framework
- Use interim laws, policies, regulations
- Have conducted contained, confined, or extended field trials
- Have allowed commercialization

Step 2. Mapping Countries to Policy Situations and Policy Objectives

As a second step we followed an approach similar to the one outlined by Trigo (2003). Trigo uses a set of variables to rank countries in terms of their current potential to implement biotechnology or plant breeding. With the variables included in his framework, Trigo classifies countries according to three policy situations (or stages), ranked here from more to less advanced capacity. We followed the same approach in our ranking (Table B.1).

Appendix C: Tables

TABLE C.1 Economic performance indicators by country for *Bacillus thuringiensis* (Bt) and conventional cotton

COUNTRY	TECHNOLOGY	YIELD (KG/HA)	ECONOMIC PERFORMANCE INDICATOR			
			Gross margin (US$/ha)	Seed costs (US$/ha)	Pesticide cost (US$/ha)	Management and labor costs (US$/ha)
South Africa	Conventional	879.57 (*n* = 7)	50.22 (*n* = 5)	20.09 (*n* = 5)	30.33 (*n* = 7)	43.34 (*n* = 3)
	Bt	1,133.00 (*n* = 7)	107.47* (*n* = 5)	39.53*** (*n* = 5)	14.66*** (*n* = 7)	43.19 (*n* = 3)
India	Conventional	1,315.31 (*n* = 96)	294.09 (*n* = 55)	24.13 (*n* = 27)	113.89 (*n* = 47)	221.69 (*n* = 38)
	Bt	1,982.77*** (*n* = 76)	389.52* (*n* = 42)	80.43*** (*n* = 27)	79.73*** (*n* = 37)	305.86 *** (*n* = 26)
China	Conventional	2,277.27 (*n* = 15)	295.11 (*n* = 24)	49.08 (*n* = 6)	163.96 (*n* = 7)	1,163.98 (*n* = 12)
	Bt	2,342.89 (*n* = 27)	–58.67*** (*n* = 17)	62.93 (*n* = 7)	46.48*** (*n* = 9)	939.94 *** (*n* = 19)
Australia	Conventional	1,764.31 (*n* = 13)	—	— —	326.70 (*n* = 13)	—
	Bt	1,788.59 (*n* = 13)	—	112.96 (*n* = 6)	254.79** (*n* = 13)	—
United States	Conventional	1,055.92 (*n* = 20)	1,047.20 (*n* = 17)	36.19 (*n* = 16)	138.39 (*n* = 17)	—
	Bt	1,064.63 (*n* = 16)	938.46 (*n* = 13)	116.54*** (*n* = 13)	116.23 (*n* = 13)	—

Source: Finger et al. (2011).

Notes: Comparisons are made using the Mann-Whitney U-test. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively. kg/ha = kilograms per hectare; *n* = number of observations; US$/ha = US dollars per hectare. A dash indicates that no data are available.

TABLE C.2 Genetic modification research and commercialized projects, 2003–2010

CROP	TECHNOLOGY TYPE	RESEARCH PROJECTS AND AREAS OF INTEREST AFRICAWIDE, 2003–2005	ONGOING RESEARCH PROJECTS, 2010	COMMERCIAL RELEASE, 2010
Bananas	PQ	Extended shelf life		
	FR	Resistance to *Sigatoka* fungus		
	IR	Nematode resistance		
	IR	Weevil resistance		
	BR	Bacteria resistance	Uganda	
	NE		Uganda	
Cassava	PQ	Decreased postharvest deterioration	South Africa	
	PQ	Novel starches		
	VR	Resistance to mosaic virus	Egypt, Kenya, Uganda, Zimbabwe	
	NE		Kenya, Nigeria, Uganda	
Cocoa	FR	Resistance to witches' broom and frosty pod rot funguses		
Cotton	AP	Drought tolerance	Egypt	
	HT		South Africa	South Africa
	IR	Resistance to bollworm	Kenya, Nigeria, Uganda, Zimbabwe	Burkina Faso, South Africa
	IR/HT		South Africa	South Africa
Cowpeas	AP	Drought tolerance		
	AP	Productivity enhancement		
	IR	Resistance to cowpea aphid–borne mosaic	Ghana	
Cucumbers, melons, squash	VR		Egypt	
Groundnuts	AP	Drought tolerance, Aflatoxin control		
	VR	Resistance to rosette and clump viruses		
	IR	Control of storage insects (weevils)		
	VR	Resistance to tobacco streak virus		
	HT	Herbicide resistance		
Maize	HT	Herbicide resistance	South Africa	
	IR	Resistance to stem borer	South Africa, Zimbabwe	Egypt, South Africa
	VR	Resistance to maize streak virus		
	AP	Drought tolerance	Kenya, Mozambique, South Africa, Tanzania, Uganda	
	FR	Resistance to *Fusarium* and *Stenocarpella* funguses		
	HT	Glyphosate resistance		South Africa

CROP	TECHNOLOGY TYPE	RESEARCH PROJECTS AND AREAS OF INTEREST AFRICAWIDE, 2003–2005	ONGOING RESEARCH PROJECTS, 2010	COMMERCIAL RELEASE, 2010
	PQ	Vitamin enhancement		
	IR/DT		South Africa	
	HT/Bt			South Africa
Potatoes	IR		Egypt, South Africa	
Rice	IR	Insect resistance		
	PQ	New Rice for Africa (NERICA)		
	VR	Resistance to rice yellow mottle virus (RYMV)		
	FR	Resistance to *Pyriculariose* fungus		
Sugarcane	AP		South Africa	
Sweet potatoes	VR	Resistance to feathery mottle virus	Kenya, Zimbabwe	
Sorghum	PQ	Nutrition enhancement	Kenya, Nigeria, South Africa	
	IR	Resistance to *Striga*		
Soybeans				South Africa
Tomatoes	VR	Resistance to tomato yellow leaf curl virus (TYLCV)	Egypt	
	PQ	Delayed ripening		
	IR	Nematode resistance		

Sources: Atanassov et al. (2004); Cohen et al. (2006); Karembu, Nguthi, and Ismail (2009).

Note: AP = agronomic property; BR = bacteria-resistant; Bt = *Bacillus thuringiensis;* DT = drought-tolerant; FR = fungus-resistant; HT = herbicide-tolerant; IR = insect-resistant; NE = nitrogen efficient; PQ = product-quality; VR = virus-resistant.

TABLE C.3 Transgenic research of CGIAR, 2008

CENTER	CENTER HEADQUARTERS	CROP	TRAIT (RESISTANCE)	RESEARCH	REGULATORY STATUS
Biodiversity	Italy	Musa	Pests (weevils, nematodes), disease	Gene discovery and characterization	Laboratory
International Center for Tropical Agriculture (CIAT)		Beans	Agronomic	Transformation (particle bombardment and Agrobacterium) Backcrossing on wild species	Greenhouse
		Cassava	Insects	Transformation (Agrobacterium) of clones used by small farmers	Field trials
			Modified starch, early flowering, beta-carotene		
		Rice	Viruses, diseases		Field trials
			Abiotic stress (flooding, acidic soils, high elevation)	Transformation (Agrobacterium) of recalcitrant cultivars into local cultivars with target trait	Laboratory
			Drought	Gene discovery (with CIMMYT, IRRI)	Laboratory
International Maize and Wheat Improvement Center (CIMMYT)	Mexico	Maize	Insects (*Bacillus thuringiensis,* Bt)	Gene characterization (target insect compatibility)	Greenhouse
				Transformation and conventional backcrossing	
		Wheat	Drought	Transcription factor and promoter characterization	Laboratory
				Genetic and molecular analysis for transmission and expression	Laboratory
			Agronomic	Transformation system development (Agrobacterium)	Laboratory
International Potato Center (CIP)	Peru	Potatoes	Insects (Bt)	Cultivar development	Field trials
			Diseases (late blight)	Cultivar development	
		Sweet potatoes	Viruses	Cultivar development	
			Insects, especially weevils	Gene discovery and characterization	
			Modified starch	Cultivar development	Field trials
International Centre for Agricultural Research in Dry Areas (ICARDA)	Syria	Chickpeas	Diseases, abiotic stress	Transformation (Agrobacterium)	Laboratory
		Lentils	Diseases, abiotic stress	Transformation (Agrobacterium)	Laboratory
		Barley	Diseases, abiotic stress	Transformation (Agrobacterium): Variety development	
		Wheat	Abiotic stress (salt drought)	Gene discovery and characterization: Transformation (Agrobacterium)	Laboratory

CENTER	CENTER HEADQUARTERS	CROP	TRAIT (RESISTANCE)	RESEARCH	REGULATORY STATUS
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	India	Groundnuts	Diseases, viruses	Tissue culture protocol	Field trials
		Pigeon peas	Insects (Bt)	Tissue culture protocol	Field trials
		Sorghum	Insects (Bt)	Tissue culture protocol	Field trials
		Chickpeas	Insects (Bt)	Tissue culture protocol	Field trials
		(Non-crop-specific)	Viruses, insects, funguses, drought, nutrition	Searching genes for further use in cultivar development	Laboratory
International Institute of Tropical Agriculture (IITA)	Nigeria	Musa	Viruses, bacteria, funguses	Transformation (Agrobacterium)	Laboratory
		Cassava	Viruses	Transformation	Laboratory
		Cowpeas	Insects (Bt)	Transformation	Laboratory
International Livestock Research Institute (ILRI)	Kenya	—		Molecular diagnostics for disease detection	
		—		Transformation of bacteria and viruses to develop a livestock vaccine against East Coast fever	
International Rice Research Institute (IRRI)	Philippines	Rice	Blight, insects (Bt)	Transformation	
			Beta-carotene	Cultivar development	Confined field trials

Source: Okusu (2009).

Notes: CGIAR was formerly an acronym for the Consultative Group on International Agricultural Research; now the group is simply called CGIAR. A dash indicates that no data are available.

TABLE C.4 Numbers and education levels of plant biotechnologists and breeders in Africa, 2001–2007

AFDB REGION, COUNTRY	YEAR	EDUCATION LEVELS OF PLANT BIOTECHNOLOGISTS				EDUCATION LEVELS OF PLANT BREEDERS			
		BS	MS	PhD	Total	BS	MS	PhD	Total
Central									
Cameroon	2003	6	5	7	18	13	12	13	38
Gabon	2005	2	6	1	9	0	3	5	8
Subtotal		8	11	8	27	13	15	18	46
Eastern									
Eritrea	2005	0	1	0	1	3	9	28	40
Ethiopia	2004	9	7	14	30	50	144	214	408
Kenya	2005	10	11	0	21	20	36	7	63
Sudan	2001	5	10	2	17	25	31	2	58
Uganda	2001	2	4	0	6	12	6	2	20
Subtotal		26	33	16	75	110	226	253	589
Northern									
Algeria	2005	27	58	126	211	42	62	210	314
Morocco	2005	7	5	0	12	11	28	2	41
Tunisia	2004	25	29	3	58	16	30	4	50
Subtotal		59	92	129	281	69	120	216	405
Southern									
Angola	2003	1	0	1	2	3	2	5	10
Botswana	2005	0	0	2	2	3	1	0	4
Malawi	2001	—	—	—	—	11	18	12	41
Mozambique	2001	—	—	—	—	5	8	15	28
Namibia	2005	0	0	1	1	4	7	8	19
Zambia	2001	1	0	0	1	10	10	6	26
Zimbabwe	2001	5	5	3	13	4	13	24	41
Subtotal		7	5	7	19	40	59	70	169
Western									
Benin	2005	3	0	0	3	7	8	4	19
Burkina Faso	2005	3	3	0	6	17	5	15	37
Côte d'Ivoire	2005	7	6	6	19	12	16	14	42
Ghana	2005	8	12	2	22	22	17	4	43
Mali	2001	1	2	2	5	11	17	12	40
Nigeria	2007	24	16	5	45	58	50	30	138
Senegal	2004	2	0	0	2	5	5	0	10
Sierra Leone	2004	1	2	0	3	1	4	1	6
Togo	2005	1	0	1	2	1	10	0	11
Subtotal		50	41	16	107	134	132	80	346
Total		150	182	176	509	366	552	637	1,555

Source: FAO-GIPB (2011).

Notes: AfDB = African Development Bank; regional classifications are based on AfDB categories, not those of the Food and Agriculture Organization of the United Nations, which may be different. Dash = data not available. In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

TABLE C.5 Relative intensity of human resource availability in Africa, 2014

COUNTRY	HUMAN RESOURCE AVAILABILITY INDICATOR			
	Plant biotechnologists per 100,000 hectares of arable land	Plant breeders per 100,000 hectares of arable land	Plant biotechnologists per million inhabitants	Plant breeders per million inhabitants
Algeria	2.8	4.1	6.8	10.1
Angola	0.1	0.3	0.1	0.7
Benin	0.1	0.8	0.4	2.5
Botswana	0.5	1.1	1.1	2.3
Burkina Faso	0.1	0.9	0.5	3.0
Cameroon	0.3	0.6	1.1	2.3
Côte d'Ivoire	0.6	1.3	1.1	2.4
Eritrea	0.2	7.6	0.3	10.3
Ethiopia	0.3	3.8	0.4	6.0
Gabon	2.8	2.5	7.5	6.7
Ghana	0.6	1.1	1.1	2.1
Kenya	0.4	1.3	0.7	2.0
Malawi	—	1.9	—	3.4
Mali	0.1	0.9	0.5	3.9
Morocco	0.1	0.5	0.4	1.4
Mozambique	—	0.7	—	1.5
Namibia	0.1	2.3	0.5	10.0
Nigeria	0.2	0.5	0.4	1.1
Senegal	0.1	0.4	0.2	0.9
Sierra Leone	0.6	1.1	0.6	1.2
Sudan	0.1	0.3	0.5	1.7
Togo	0.1	0.4	0.4	2.0
Tunisia	2.1	1.8	6.0	5.2
Uganda	0.1	0.4	0.2	0.8
Zambia	0.0	0.5	0.1	2.4
Zimbabwe	0.4	1.3	1.0	3.2

Source: Compiled by authors.
Notes: Dash = data not available. In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

TABLE C.6 African biotechnology capacity indicators, 2014

REGION	COUNTRY	OVERALL INNOVATIVE CAPACITY	IP SITUATION	ECONOMY WIDE STATUS	MARKET SIZE	STRENGTH OF PRIVATE SECTOR	BIOTECH CAPACITY	BIOSAFETY CAPACITY
Central	Cameroon	+++	+	+++	++	+++	+	+
	Central African Republic	+	+	++	++	++	+	+
	Chad	+	+	++	+++	++	+	+
	Congo, Democratic Republic of	++	++	++	++	++	+	+
	Congo, Republic of	++	++	++	+++	++	+	+
	Equatorial Guinea	+	+	+++	+	++	+	+
	Gabon	++	+	++	+	++	+	+
Eastern	Burundi	++	++	+	++	+++	+	+
	Comoros	+	+	++	++	++	+	+
	Djibouti							
	Eritrea	+	+	++	++	++	+	+
	Ethiopia	+++	++	++	+++	++	++	++
	Kenya	+++	+++	++	++	++	++	++
	Rwanda	++	++	++	+++	++	+	+
	Seychelles	++	++	++	+	++	+	+
	Somalia	++	+	+++	++	+++	+	+
	Sudan	+++	++	+++	+++	++	+	+
	Tanzania	+++	++	++	+++	++	++	+
	Uganda	+++	++	++	+++	++	++	++
Northern	Algeria	+++	+++	+++	++	++	+++	+
	Egypt	+++	+++	+++	++	+++	+++	++
	Libya	++	++	+++	++	+++	+	+
	Mauritania	++	+	++	++	++	+	+
	Morocco	+++	+++	+++	+++	++	++	+
	Tunisia	+++	+++	+++	++	++	++	+

Southern	Angola	++	++	+++	++	++	+	+
	Botswana	+++	++	++	++	++	+	+
	Lesotho	++	++	++	++	++	+	+
	Madagascar	++	++	++	++	++	+	+
	Malawi	++	+++	++	++	++	+	+
	Mauritius	++	++	++	++	++	+	+
	Mozambique	++	+	+++	+++	++	+	+
	Namibia	+++	+++	++	++	++	+	+
	South Africa	+++	+++	++	++	++	+++	++
	Swaziland	++	++	++	++	++	+	+
	Zambia	++	+++	++	++	++	++	++
	Zimbabwe	+++	+++	++	++	+++	++	++
Western	Benin	++	+	++	+++	++	+	+
	Burkina Faso	++	+	++	+++	++	+	++
	Cape Verde	++	+	++	+	++	+	+
	Côte d'Ivoire	+++	+	++	++	++	+	+
	Gambia	+	++	++	++	++	+	+
	Ghana	+++	++	++	+++	++	+	+
	Guinea	+	+	++	++	++	+	+
	Guinea-Bissau	++	+	+	++	++	+	+
	Liberia	+	++	++	++	+++	+	+
	Mali	++	+	++	+++	+++	+	+
	Niger	++	+	++	+++	++	+	+
	Nigeria	+++	++	+++	+++	++	++	++
	São Tomé and Príncipe	+	++	+++	+	++	+	+
	Senegal	+++	+	++	++	++	++	+
	Sierra Leone	++	++	++	++	++	+	+
	Togo	++	+	++	+++	++	+	+

Source: Estimated by authors.

Notes: [dark green box] = nonselective biotechnology importers; [light green box] = selective biotechnology importers; [pale box] = biotechnology tool users. + to +++ indicates lowest to highest capacity. In this table, "Sudan" refers to the former Sudan, which is now two independent nations, Sudan and South Sudan.

TABLE C.7 A sampling of communication and outreach initiatives in Africa, 2009

PROGRAM OR INITIATIVE	AREA OF FOCUS
International Service for the Acquisition of Agri-biotech Applications (ISAAA) *Afri*Center	*Afri*Center focuses on communication and knowledge sharing through collection, packaging, and dissemination of knowledge and through networking, building partnerships, and fostering joint initiatives to share resources, experiences, and expertise on crop biotechnology. It coordinates a network of Biotechnology Information Centers (BICs) located in Egypt (EBIC for Arab-speaking people), Mali and Burkina Faso (Mali-BIC for French-speaking), and East and Central Africa (ECABIC) for English- and Swahili-speaking). www.isaaa.org/kc
Public Understanding of Biotechnology (PUB)	PUB is operated by the South African Agency of Science and Technology Advancement (SAATA) with the aim of promoting a clear understanding of biotechnology's potential and ensuring broad public awareness to stimulate dialogue and debate on biotechnology. www.pub.ac.za
Africabio	Africabio is a biotechnology stakeholders' association whose key role is to provide accurate information and create awareness, understanding, and knowledge on biotechnology and biosafety in South Africa and the African region. www.africabio.com
African Biotechnology Stakeholders Forum (ABSF)	ABSF's focus is on creating an innovative and enabling biotechnology environment in Africa through education, enhanced understanding, and awareness creation. www.absfafrica.org
Africa Harvest Biotech Foundation International (Africa Harvest)	Africa Harvest aims at building the capacity of scientists and of science and agricultural organizations in integrating communication strategies into their research activities and also at helping the news media improve their coverage of science and agricultural issues. www.ahbfi.org
National Biotechnology Awareness Creation Strategy (BioAWARE-Kenya)	Spearheaded by the Agricultural Sector Coordinating Unit (ASCU) under the Ministry of Agriculture, BioAWARE-Kenya aims at providing a knowledge base for informed decisionmaking to hasten the deployment of biotechnology through a participatory awareness creation process.
Open Forum on Agricultural Biotechnology (OFAB) in Africa	OFAB's focus is on strengthening interinstitutional networking and sharing of credible, sound, and factual biotechnology information through a platform that brings together stakeholders in biotechnology and enables interactions between scientists, journalists, the civil society, industrialists, and policymakers. www.ofabafrica.org
Réseau des Communicateurs ouest-Africains sur la Biotechnologie (RECOAB)	RECOAB is a network of both Francophone and Anglophone West African journalists that builds capacity and provides factual and balanced information on biotechnology to enable informed participation in debates on biotechnology. cyrpayim@hotmail.com
Biotechnology-Ecology Research and Outreach Consortium (BioEROC)	BioEROC aims at delivering relevant research, training, management, and outreach services in natural resources to promote responsible and relevant applications of biotechnology and its products
Burkina Biotech Association	Burkina Biotech Association was created by Burkina Faso scientists with the objective of providing a forum for stakeholders in the field of biotechnology to dialogue and voice their opinions and concerns. bba@fasonet.bf

Source: Karembu, Nguthi, and Ismail (2009).

REFERENCES

ABS (Africa Biofortified Sorghum) Project. 2014. "ABS Project: Technology Development." Accessed May 7, 2014. http://biosorghum.org/articles.php?id=56.

Adato, M., and R. Meinzen-Dick. 2003. "Assessing the Impact of Agricultural Research on Poverty and Livelihoods." *Quarterly Journal of International Agriculture* 42 (2): 149–167.

Adenle, A. 2011. "Adoption of Commercial Biotech Crops in Africa: 2nd International Conference on Biotechnology and Food Science." *International Proceedings of Chemical, Biological and Environmental Engineering* 7. Singapore: International Association of Computer Science and Information Technology Press.

Adongo, J. 2005. *Venture Capital Firms in Africa and Their Investees.* Windhoek, Namibia: Namibian Economic Policy Research Unit.

AfDB (African Development Bank). 2010. *Report: Boards of Directors of the African Development Bank and the African Development Fund Covering the Period January 1–December 31.* ADB-ADF/BG/AR/2010. Tunis.

African Union. 2001. *African Model Law on Safety in Biotechnology.* Addis Ababa. www.africa-union.org/root/AU/AUC/Departments/HRST/biosafety/DOC/level2/African%20Model%20Law%20with%20Annexes-EN.pdf.

AGRA (African Alliance for a Green Revolution in Africa). 2013. *African Agriculture Status Report, Focus on Staple Crops.* Nairobi: Alliance for a Green Revolution in Africa.

Agyei, Y. n.d. Deforestation in Sub-Saharan Africa. *African Technology Forum* 8 (1). Accessed May 2, 2014. http://web.mit.edu/africantech/www/articles/Deforestation.htm.

Alston, J., G. Norton, and P. Pardey. 1998. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Wallingford, UK: CAB International.

Altieri, M. A., and P. Rosset. 1999. "Ten Reasons Why Biotechnology Will Not Ensure Food Security, Protect the Environment, and Reduce Poverty in the Developing World." *AgBioForum* 2 (3–4): 155–162. http://agbioforum.org/v2n34/v2n34a03-altieri.htm.

Anderson, K., and L. A. Jackson. 2005. "Africa." *Journal of African Economies* 14 (3): 385–410.

Anderson, K., and E. Valenzuela. 2007. "The World Trade Organization's Doha Cotton Initiative: A Tale of Two Issues." *World Economy* 30 (8): 1281–1304.

ASA (African Science Academies). 2013. "Declaration of the 9th Annual Meeting of African Science Academies (AMASA-9)." Addis Ababa, Ethiopia, November 10–12.

Atanassov, A., A. Bahieldin, J. Brink, M. Burachik, J. I. Cohen, V. Dhawan, R. V. Ebora, J. Falck-Zepeda, L. Herrera-Estrella, J. Komen, F. C. Low, E. Omaliko, B. Odhiambo, H. Quemada, Y. Peng, M. J. Sampaio, I. Sithole-Niang, A. Sittenfeld, M. Smale, Sutrisno, R. Valyasevi, Y. Zafar, and P. Zambrano. 2004. *To Reach the Poor: Results from the ISNAR-IFPRI Next Harvest Study on Genetically Modified Crops, Public Research, and Policy Implications.* Environment and Production Technology Division Discussion Paper 116. Washington, DC: International Food Policy Research Institute.

ATPS (African Technology Policy Studies Network). 2010. *The African Manifesto for Science Technology and Innovation.* Nairobi. www.atpsnet.org/Files/the_african_manifesto_for_st&i.pdf.

Ayele, S., J. Chataway, and D. Wield 2006. "Partnerships in African Crop Biotech." *Nature Biotechnology* 24 (6): 916–621.

Bansal, S., and G. Gruère. 2010. *Labeling Genetically Modified Food in India: Economic Consequences in Four Marketing Channels.* IFPRI Discussion Paper 00946. Washington, DC: International Food Policy Research Institute. www.ifpri.org/sites/default/files/publications/ifpridp00946.pdf.

Bates, S. L., J. Zhao, R. T. Roush, and A. M. Shelton. 2005. "Insect Resistance Management in GM Crops: Past, Present, and Future." *Nature Biotech* 23 (1): 57–62.

Bayer, J. C., G. W. Norton, and J. Falck-Zepeda. 2010. "Cost of Compliance with Biotechnology Regulation in the Philippines: Implications for Developing Countries." *AgBioForum* 13 (1): 53–62.

Beintema, N., and G.-J. Stads. 2011. *African Agricultural R&D in the New Millennium: Progress for Some, Challenges for Many.* IFPRI Food Policy Report. Washington, DC: International Food Policy Research Institute.

———. 2014. "Is Africa Investing Enough?" In *IFPRI 2013 Global Food Policy Report.* Washington, DC: International Food Policy Research Institute.

Bennett, R., S. Morse, and Y. Ismael. 2006. "The Economic Impact of Genetically Modified Cotton on South African Smallholders: Yield, Profit, and Health Effects." *Journal of Development Studies* 42: 662–677.

Bennett, R., T. Buthelezi, Y. Ismael, and S. Morse. 2003. "Bt Cotton, Pesticides, Labour, and Health: A Case Study of Smallholder Farmers in the Makhathini Flats, Republic of South Africa." *Outlook on Agriculture* 32: 123–128.

Bett, C., J. Okuro Ouma, and H. De Groote. 2010. "Perspectives of Gatekeepers in the Kenyan Food Industry towards Genetically Modified Food." *Food Policy* 35 (4): 332–340.

Binenbaum, E., C. Nottenburg, P. G. Pardey, B. D. Wright, and P. Zambrano. 2003. "South-North Trade, Intellectual Property Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops." *Economic Development and Cultural Change* 51 (2): 309–335.

Bio-Innovate (Bio-resources Innovations Network for Eastern Africa Development). 2010. "Program Proposal." Accessed October 2011. http://bioinnovate-africa.org.

Biovision. 2008. "Uganda Approves National Biotech and Biosafety Policy." *Newsletter,* vol. 8 (April). Accessed April 2014. www.biovisioneastafrica.com/publications/Vision_8.pdf.

Birner, R., S. Abel Kone, N. Linacre, and D. Resnick. 2007. "Biofortified Foods and Crops in West Africa: Mali and Burkina Faso." *AgBioForum* 10 (3): 192–200. www.agbioforum.org.

BMGF (Bill & Melinda Gates Foundation). 2012. Awarded Grants online database. Accessed October 2012. www.gatesfoundation.org/How-We-Work/Quick-Links/Grants-Database.

———. 2014. Bill & Melinda Gates Foundation Opens Application: Round 13 of Grand Challenges Explorations. Accessed May 30, 2014. http://www.gatesfoundation.org/Media-Center/Press-Releases/2014/03/Bill-Melinda-Gates-Foundation-Opens-Application-Round-13-of-Grand-Challenges-Explorations.

Bouët, A., and G. Gruère. 2011. "Refining Estimates of the Opportunity Cost of Non-adoption of Bt Cotton: The Case of Seven Countries in Sub-Saharan Africa." *Applied Economic Perspectives and Policy* 33 (2): 260–279.

Bouët, A., G. Gruère, and L. Leroy. 2011. *The Price and Trade Effects of Strict Information Requirements for Genetically Modified Commodities under the Cartagena Protocol on Biosafety.* IFPRI Discussion Paper 01102. Washington, DC: International Food Policy Research Institute.

Brookes, G., and P. Barfoot. 2005. "GM Crops: The Global Economic and Environmental Impact—The First Nine Years, 1996–2004." *AgBioForum* 8 (2–3): 187–196.

Byerlee, D., and K. Fischer. 2002. "Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries." *World Development* 30 (6): 931–948.

Cabanilla, L. S., T. Abdoulaye, and J. H. Sanders. 2005. "Economic Cost of Non-adoption of Bt-Cotton in West Africa: With Special Reference to Mali." *International Journal of Biotechnology* 7: 46–61.

Carter, C. A., and G. P. Gruère. 2003. "Mandatory Labeling of Genetically Modified Food: Does It Really Provide Consumer Choice?" *AgBioForum* 6 (1–2): 68–70.

———. 2006. "International Approval and Labeling Regulations of Genetically Modified Food in Major Trading Countries." In *Regulating Agricultural Biotechnology: Economics and Policies,* edited by R. Just, J. M. Alston, and D. Zilberman, 459–480. New York: Springer.

———. 2012. "New and Existing GM Crops: In Search of Effective Stewardship and Coexistence." *Northeastern University Law Journal* 4 (1): 169–207.

Cavalieri, A., L. Cramer, J. Falck-Zepeda, and P. Zambrano. 2011. "Delivering Technologies to Small-Scale Farmers: The Case of Drought Tolerant and Water Efficient Maize for Africa." Unpublished report, International Food Policy Research Institute, Washington, DC.

CBD (Convention on Biological Diversity) Secretariat. 2000. *Cartagena Protocol on Biosafety to the Convention on Biological Diversity.* Montreal. http://bch.cbd.int/database/attachment/?id=10694.

———. 2011a. *Nagoya–Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol of Biosafety.* Montreal.

———. 2011b. *Nagoya–Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol of Biosafety: Status of Signature, and Ratification, Acceptance, Approval, or Accession.* Montreal. www.cbd.int/abs/nagoya-protocol/signatories/.

CERA. 2014. GM Crop database. Accessed May 6, 2014. www.cera-gmc.org/?action=gm_crop_database.

CGIAR 2011. "CGIAR and Agricultural Biotechnology." Accessed May 2, 2014. http://cgiar.bio-mirror.cn/impact/agribiotech.html.

Cloete, T., L. Nel, and J. Theron. 2006. "Biotechnology in South Africa." *Trends in Biotechnology* 24: 557–562.

Codex Alimentarius. 2003. "Guideline for the Conduct of Food Safety Assessment of Foods Derived from Recombinant-DNA Plants." CAC/GL 45-2003. Accessed May 6, 2014. www.codexalimentarius.org/standards/list-of-standards/.

Cohen, J. I. 2005. "Poorer Nations Turn to Publicly Developed GM Crops." *Nature* 23 (1): 27–33.

Cohen, J. I., J. Falck-Zepeda, S. Wood, U. Wood-Sichra, L. You, and P. Zambrano. 2006. *The Potential Economic Benefits of Biotechnology Innovations in East and West Africa: A Prototype Assessment Final Report for USAID Project Number: 2889-005CGIAR*. Washington DC: International Food Policy Research Institute.

Commission for Africa. 2005. *Our Common Interest: Report of the Commission for Africa.* London.

Cooke, J., and R. Downie. 2010. *African Perspectives on Genetically Modified Crops.* Washington, DC: Center for Strategic and International Studies.

Crouch, J., and P. Bloch. 2013. *Bio-Innovate Program Mid-Term Review Report 2013.* Sida Decentralised Evaluation 2013: 18. Nairobi: Swedish International Development Cooperation Agency (Sida). www.sida.se/Publications/Import/pdf/sv/Bio-Innovate-Program-Mid-Term-Review-Report-2013_3501.pdf.

De Groote, H., W. Overholt, J. O. Ouma, and S. Mugo. 2003. "Assessing the Potential Impact of Bt Maize in Kenya Using a GIS Based Model." Unpublished paper, International Association of Agricultural Economists, Milwaukee, WI, US.

De Leon, A., A. Manalo, and F. C. Guilatco. 2004. *The Cost Implications of GM Food Labeling in the Philippines.* Study commissioned by the Bureau of Food and Drugs, Department of Health, Republic of the Philippines. Manila.

Durham, B. 2009. "Public Perception of Biotechnology in South Africa." Paper presented at the conference Delivering Agricultural Biotechnology to African Farmers: Linking Economic Research to Decision-Making, Entebbe, Uganda, May, sponsored by the International Food Policy Research Institute.

Duvick, D. N. 1997. "Genetic Rates of Gain in Hybrid Maize Yields during the Past 40 Years." *Maydica* 22: 187–196.

Elbehri, A., and S. Macdonald. 2004. "Estimating the Impact of Transgenic Bt Cotton on West and Central Africa: A General Equilibrium Approach." *World Development* 32 (12): 2049–2064.

European Commission. 2010. *A Decade of EU Funded GMO Research, 2001–2010.* EUR 22273. Luxembourg: Publications Office of the European Union.

Evenson, R. E., and D. Gollin. 2003. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300 (May): 758–762.

Falck-Zepeda, J. B. 2006. "Coexistence, Genetically Modified Biotechnologies, and Biosafety: Implications for Developing Countries." *American Journal of Agricultural Economics* 88 (5): 1200–1208.

———. 2009. "Socio-economic Considerations: Article 26.1 of the Cartagena Protocol on Biosafety; What Are the Issues and What Is at Stake?" *AgBioForum* 12 (1): 90–107. http://agbioforum.org/v12n1/v12n1a09-falckzepeda.htm.

Falck-Zepeda, J. B., and P. Zambrano. 2011. "Socio-economic Considerations in Biosafety and Biotechnology Decision Making: The Cartagena Protocol and National Biosafety Frameworks." *Review of Policy Research* 28 (2): 171–195. http://dx.doi.org/10.1111/j.1541-1338.2011.00488.x.

Falck-Zepeda, J. B., D. Horna, and M. Smale. 2007. *The Economic Impact and the Distribution of Benefits and Risk from the Adoption of Insect Resistant (Bt) Cotton in West Africa.* IFPRI Discussion Paper 718. Washington, DC: International Food Policy Research Institute.

Falck-Zepeda, J. B., J. Cohen, R. Meinzen-Dick, and J. Komen. 2002. *Biotechnology and Sustainable Livelihoods: Findings and Recommendations of an International Consultation.* ISNAR Briefing Paper 54. The Hague: International Service for National Agricultural Research.

Falck-Zepeda, J., P. Zambrano, J. I. Cohen, O. Borges, E. P. Guimarães, D. Hautea, J. Kengue, and J. Songa. 2008. *Plant Genetic Resources for Agriculture, Plant Breeding, and Biotechnology: Experiences from Cameroon, Kenya, the Philippines, and Venezuela.* IFPRI Discussion Paper 762. Washington, DC: International Food Policy Research Institute.

FAO (Food and Agriculture Organization of the United Nations). 2000. *Multilateral Trade Negotiations on Agriculture: A Resource Manual / Trips Agreement.* Rome. http://www.fao.org/docrep/003/x7355e/x7355e07.htm.

———. 2001. *International Treaty on Plant Genetic Resources for Food and Agriculture.* Rome. www.fao.org/ag/cgrfa/itpgr.htm#text.

———. 2004. *Preliminary Review of Biotechnology in Forestry, Including Genetic Modification.* Forest Genetic Resources Working Paper FGR/59E. Rome.

———. 2006. "Towards the Sustainable Use of Plant Genetic Resources Food and Agriculture (PGRFA): Strengthening Plant Breeding." Paper prepared for the Working Group on PGRFA of the Commission on Genetic Resources for Food and Agriculture at FAO. CGRFA/WG-PGR-2/03/2. Rome.

———. 2011a. "Biotechnologies for Agricultural Development." *Proceedings of the FAO International Technical Conference on Agricultural Biotechnologies in Developing Countries: Options and Opportunities in Crops, Forestry, Livestock, Fisheries and Agro-industry to Face the Challenges of Food Insecurity and Climate Change (ABDC-10).* Rome.

———. 2011b. *The State of Food Insecurity in the World.* Rome.

———. 2012. *The State of Food and Agriculture: Investing in Agriculture for a Better Future.* Rome. www.fao.org/docrep/017/i3028e/i3028e.pdf.

———. 2014a. FAO GM Foods Platform. Accessed April 2014. www.fao.org/food/food-safety-quality/gm-foods-platform/en/.

———. 2014b. FAOStat database. Rome. Accessed March 2014. http://faostat.fao.org/.

FAO, WFP, and IFAD (FAO, World Food Programme, and International Fund for Agricultural Development). 2012. *The State of Food Insecurity in the World 2012: Economic Growth Is Necessary but Not Sufficient to Accelerate Reduction of Hunger and Malnutrition.* Rome. www.fao.org/docrep/016/i3027e/i3027e.pdf.

FAO-GIPB (Food and Agriculture Organization of the United Nations–Global Partnership Initiative for Plant Breeding Capacity Building). 2011. Survey Database from the Plant Breeding and Related Biotechnology Capacity Assessments. Online database. Accessed October 2011. http://gipb.fao.org/Web-FAO-PBBC/.

FARA (Forum for Agricultural Research in Africa). 2011. *Status of Biotechnology and Biosafety in Sub-Saharan Africa.* A FARA 2009 Study Report. Accra, Ghana.

———. n.d. "Biotechnology Management in Africa." Accessed March 2014. www.fara-africa.org/media/uploads/File/sabima/biotechdatabase__online.doc.

Fernandez-Cornejo, J. 2004. *Improved Seed Is a Major Contributor to Crop Yield Gains and Agricultural Productivity in the Seed Industry in U.S. Agriculture.* Agriculture Information Bulletin AIB786. Washington, DC: Economic Research Service.

Ferroni, M. 2010. "Can Private Sector R&D Reach Small Farmers?" *Proceedings of the 2009 Annual Conference, Crawford Fund,* 1–10. Accessed May 6, 2014. www.syngentafoundation.org/__temp/Can_private_sector_R&D_reach_small_farmers.pdf.

Fiedler, J. L., E. Kikulwe, and E. Birol. 2013. *An Ex Ante Analysis of the Impact and Cost Effectiveness of Biofortified High Provitamin A and High Iron Banana in Uganda.* IFPRI Discussion Paper 01277. Washington, DC: International Food Policy Research Institute.

Finger, R., N. El Benni, T. Kaphengst, C. Evans, S. Herbert, B. Lehmann, S. Morse, and Nataliya Stupak. 2011. "A Meta Analysis on Farm-Level Costs and Benefits of GM Crops." *Sustainabilit*y 3: 743–762.

Fuglie, K., and C. Pray. 2000. "The Private Sector and International Technology Transfer in Agriculture." In *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications,* edited by K. Fuglie and D. E. Schimmelpfenning, 269–299. Ames, IA, US: Iowa State University Press.

Furman, J. L., M. E. Porter, and S. Stern. 2002. "The Determinants of National Innovative Capacity." *Research Policy* 31 (6): 899–933.

GAFSP (Global Agriculture and Food Security Program). 2014. "Project Implementation Update." Accessed May 2, 2014. www.gafspfund.org/sites/gafspfund.org/files/Documents/ImplementationUpdate_Feb%206_FINAL%202.pdf.

Garforth, K. 2011. "Considerations of Capacity Building Needs and Initiatives Relating to the Implementation of the Nagoya–Kuala Lumpur Supplementary Protocol on Liability and Redress." Paper presented at the Coordination Meeting for Governments and Organizations Implementing and/or Funding Biosafety Capacity-Building Activities, Chisinau, Republic of Moldova, April 4–6.

Gbègbèlègbè, D. S., J. Lowenberg-DeBoer, R. Adeoti, J. Lusk, and O. Coulibaly. 2009. "The Estimated Ex Ante Economic Impact of Bt Cowpea in Niger, Benin, and Northern Nigeria." In Agricultural Biotechnology Stakeholders Forum (ABSF), *Harnessing the Potential of Agricultural Biotechnology for Food Security and Socio-economic Development in Africa*: *Proceedings of the 1st All Africa Congress on Biotechnology.* Nairobi: ABSF.www.absfafrica.org/downloads/Congress%20_Proceedings_Publication.pdf.

GCARD (Global Conference on Agricultural Research for Development). 2010. "Benefitting the Poor through Public-Private Partnerships for Innovation and Action." Background paper for the Global Conference on Agricultural Research for Development, Montpellier, France, March 28–30.

GMO Safety News. 2010. "UN Conference Adopts International Liability Rules for Ecological Damage Resulting from Genetically Modified Organisms." October 2011. www.gmo-safety.eu/news/1233.conference-adopts-international-liability-rules-ecological-damage-resulting-genetically-modified-organisms.html.

Godfray, H.C.J. 2011. "Food and Biodiversity." *Science* 333: 1231–1232.

Godfray, H.C.J., J. R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas, and C. Toulmin. 2010. "Food Security: The Challenge of Feeding 9 Billion People." *Science* 327 (5967): 812.

Golan, E., and F. Kuchler. 2011. "The Effect of GM Labeling Regime on Market Outcome." In *Genetically Modified Food and Global Welfare,* edited by C. Carter, G. Moschini, and I. M. Sheldon. Frontiers of Economics and Globalization, vol. 10. Bingley, UK: Emerald.

Gouse, M., J. Kirsten, and L. Jenkins. 2003. "Bt Cotton in South Africa: Adoption and the Impact on Farm Incomes amongst Small-Scale and Large-Scale Farmers." *Agrekon* 42: 15–28.

Gouse, M., C. E. Pray, and D. Schimmelpfennig. 2004. "The Distribution of Benefits from Bt Cotton Adoption in South Africa." *AgBioForum* 7 (4): 187–194.

Gouse, M., J. Kirsten, B. Shankar, and C. Thirtle. 2005. "Bt Cotton in Kwazulu Natal: Technological Triumph but Institutional Failure." *AgBiotechNe*t 7 (134): 1–7.

Gouse, M., C. E. Pray, D. Schimmelpfennig, and J. Kirsten. 2006. "Three Seasons of Subsistence Insect-Resistant Maize in South Africa: Have Smallholders Benefited?" *AgBioForum* 9 (1): 15–22.

Graff, G., S. Cullen, K. Bradford, D. Zilberman, and A. Bennett. 2003. "The Public Private Structure of Intellectual Property Ownership in Agricultural Biotechnology." *Nature Biotechnology* 21 (9): 989–995.

Gruère, G. P. 2006a. *An Analysis of Trade Related Regulations of Genetically Modified Food and Their Effects on Developing Countries.* Environment and Production Technology Division Discussion Paper 147. Washington, DC: International Food Policy Research Institute. www.ifpri.org/sites/default/files/publications/eptdp147.pdf.

———. 2006b. "A Preliminary Comparison of the Retail Level Effects of Genetically Modified Food Labeling Policies in Canada and France." *Food Policy* 31: 148–161.

———. 2009. "Asynchronous Approvals of GM Products, Price Inflation, and the Codex Annex: What Low Level Presence Policy for APEC Countries?" Paper presented at the International Agricultural Trade Research Consortium Summer Symposium, St. Paul, MN, US. Accessed May 6, 2014. http://iatrc.software.umn.edu/activities/symposia/2009Seattle/seattle-Gruere.pdf.

———. 2011a. "Global Welfare and Trade-Related Regulations of GM Food: Biosafety, Markets, and Politics." In *Genetically Modified Food and Global Welfare,* edited by C. Carter, G. Moschini, and I. M. Sheldon. Frontiers of Economics and Globalization, vol. 10. Bingley, UK: Emerald.

———. 2011b. *Asynchronous Approvals of GM Products and the Codex Annex: What Low Level Presence Policy for Vietnam?* IPC Discussion Paper. Washington, DC: International Agriculture and Food Trade Policy Council. www.agritrade.org/Publications/documents/LLPVietnam.pdf.

Gruère, G. P., and S. R. Rao. 2007. "A Review of International Labeling Policies of Genetically Modified Food to Evaluate India's Proposed Rule." *AgBioForum* 10 (1): 51–64.

Gruère, G. P., and M. W. Rosegrant. 2008. "Assessing the Implementation Effects of the Biosafety Protocol's Stringent Information Requirements in Countries of the Asia Pacific Economic Cooperation." *Review of Agricultural Economics* 30 (2): 214–232.

Gruère, G. P., and D. Sengupta. 2009a. "The Effects of GM-Free Private Standards on Biosafety Policymaking in Developing Countries." *Food Policy* 34 (5): 399–406.

Gruère, G. P., and D. Sengupta. 2009b. *Biosafety and Perceived Commercial Risks: The Role of GM Free Private Standards.* IFPRI Discussion Paper 00847. Washington, DC: International Food Policy Research Institute. www.ifpri.org/sites/default/files/publications/ifpridp00847.pdf.

———. 2010. "Reviewing South Africa's Marketing and Trade Related Policies for Genetically Modified Products." *Development Southern Africa* 27 (3): 333–352.

Gruère, G. P., A. Bouët, and S. Mevel. 2011. "International Trade and Welfare Effects of Biotechnology Innovations: GM Food Crops in Bangladesh, India, Indonesia, and the Philippines." In *Genetically Modified Food and Global Welfare,* edited by C. Carter, G. Moschini, and I. M. Sheldon, 283–308. Frontiers of Economics and Globalization, vol. 10. Bingley, UK: Emerald Group Publishing Limited.

Gruère, G. P., C. A. Carter, and Y. H. Farzin. 2008. "What Labeling Policy for Consumer Choice?: The Case of Genetically Modified Food in Canada and Europe." *Canadian Journal of Economics* 41 (4): 1472–1497.

———. 2009. "Explaining International Differences in Genetically Modified Food Labeling Regulations." *Review of International Economics* 17 (3): 393–408.

Guimaraes, E. P., E. Kueneman, and M. J. Carena. 2006. "Assessment of National Plant Breeding and Biotechnology Capacity in Africa and Recommendations for Future Capacity Building." *HortScience* 41 (1): 50–52.

HarvestChoice. 2010. HarvestChoice website. Accessed October 2011. http://harvestchoice.org.

———. 2011. *High P Fixation (Percent or Area).* Washington, DC: International Food Policy Research Institute; St. Paul, MN, US: University of Minnesota. http://harvestchoice.org/node/4961.

Headey, D. D., and P. Dorosh. 2011. "The Theory and Empirics of Africa's Economic Transformation: How Far Do They Take Us?" Paper presented at the IFPRI–University of Ghana conference Understanding Economic Transformation in Sub-Saharan Africa, Accra, Ghana, May 10–11.

Hokanson, K., N. C. Ellstrand, J. T. Ouedraogo, P. A. Olweny, B. A. Schaal, and A. F. Raybould. 2009. "Biofortified Sorghum in Africa: Using Problem Formulation to Inform Risk Assessment." *Nature Biotech* 28 (9): 900–903.

Holmen, H. 2006. "Myths about Agriculture, Obstacles to Solving the African Food Crisis." *European Journal of Development Research* 18 (3): 453–480.

Horna, D., P. Zambrano, and J. Falck-Zepeda. 2013. *Socioeconomic Considerations in Biosafety Decisionmaking Methods and Implementation.* Washington, DC: International Food Policy Research Institute.

Huang, J., R. Hu, S. Rozelle, F. Qiao, and C. E. Pray. 2002. "Transgenic Varieties and Productivity of Smallholder Cotton Farmers in China." *Australian Journal of Agricultural and Resource Economics* 46: 367–387.

Huesing, J., and L. English. 2004. "The Impact of Bt Crops on the Developing World." *AgBioForum* 7 (1–2): 84–95.

Hutchison, W. D., R. C. Venette, D. Bergvinson, and J. van den Berg. 2008. "Pest Distribution Profile: *Chilo Partellus*." HarvestChoice. Accessed May 6, 2014. http://harvestchoice.org/sites/default/files/downloads/publications/Chilo%20profile-HC001_v05.pdf.

Hyman, G., S. Fujisaka, P. Jones, S. Wood, M. C. de Vicente, and J. Dixon. 2008. "Strategic Approaches to Targeting Technology Generation: Assessing the Coincidence of Poverty and Drought-Prone Crop Production." *Agricultural Systems* 98 (1): 50–61.

ICAC (International Cotton Advisory Committee). 2010. *World Cotton Trade.* Washington, DC.

IFPRI (International Food Policy Research Institute). 2005. "Rapid Assessment Report." Unpublished, IFPRI, Washington, DC.

———. 2011. Linked Open Data—The Statistics of Public Expenditure for Economic Development (SPEED). Online database. Accessed November 2011. http://data.ifpri.org/lod/indicator.

ISAAA (International Service for the Acquisition of Agri-biotech Applications). 2010. *Crop Biotech Update.* Accessed May 6, 2014. www.isaaa.org/kc/cropbiotechupdate/newsletter/default.asp?Date=5/21/2010.

———. 2011. *Media, Messages, and Metaphors: How Philippine Newspapers Define Agri-biotech.* Biotech Communication Series. Los Baños, Laguna, Philippines: ISAAA SEAsia Center.

Ismael, Y., R. Bennett, and S. Morse. 2002. "Farm-Level Economic Impact of Biotechnology: Smallholder *Bt* Cotton Farmers in South Africa." *Outlook on Agriculture* 31: 107–111.

Jaffe, G. 2005. "Implementing the Cartagena Biosafety Protocol through National Biosafety Regulatory Systems: An Analysis of Key Unresolved Issues." *Journal of Public Affairs* 5: 299–311.

James, C. 1998. *Global Review of Commercialized Transgenic Crops: 1998.* ISAAA Brief 8. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2000. *Global Status of Commercialized Transgenic Crops: 2000.* ISAAA Brief 23. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2002. *Preview: Global Status of Commercialized Transgenic Crops: 2002.* ISAAA Brief 27. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2004. *Preview: Global Status of Commercialized Biotech/GM Crops: 2004.* ISAAA Brief 32. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

James, C. 2006. *Global Status of Commercialized Biotech/GM Crops: 2006.* ISAAA Brief 35. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2007. *Global Status of Commercialized Biotech/GM Crops: 2007.* ISAAA Brief 37. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2008. *Global Status of Commercialized Biotech/GM Crops: 2008.* ISAAA Brief 39. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2009. *Global Status of Commercialized Biotech/GM Crops: 2009.* ISAAA Brief 41. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2010. *Global Status of Commercialized Biotech/GM Crops: 2010.* ISAAA Brief 42. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2012. *Global Status of Commercialized Biotech/GM Crops: 2012.* ISAAA Brief 44. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

———. 2013. *Global Status of Commercialized Biotech/GM Crops: 2013.* ISAAA Brief 46. Ithaca, NY, US: International Service for the Acquisition of Agri-biotech Applications.

Jank, B., and J. Rath. 2014. "Codex Guideline and Food and Agriculture Organization Database on Low-Level Presence of Genetically Modified Plants." *Trends in Biotechnology* 32 (4): 168–169.

Juma, C. 2011. *The New Harvest: Agricultural Innovation in Africa.* New York: Oxford University Press.

Juma, C., and I. Serageldin, eds. 2007. *Freedom to Innovate: Biotechnology in Africa's Development.* A report of the high-level African panel on modern biotechnology. Addis Ababa: African Union; Pretoria: New Partnership for Africa's Development.

Kalaitzandonakes, N. 2011. *The Economic Impacts of Asynchronous Authorizations and Low Level Presence: An Overview.* IPC Discussion Paper. Washington, DC: International Food and Agricultural Trade Policy Council. www.agritrade.org/Publications/documents/LLPOverview.pdf.

Karembu, M., F. Nguthi, and H. Ismail. 2009. *Biotech Crops in Africa: The Final Frontier.* Nairobi: International Service for the Acquisition of Agri-biotech Applications *Afri*Center.

Karembu, M., F. Nguthi, K. Ogero, and D. Wafula. 2012. *Status of Agricultural Biotechnology in Kenya: A Handbook for Policy Makers.* Nairobi: International Service for the Acquisition of Agri-biotech Applications, *Afri*Center and National Biotechnology Awareness Creation Strategy, and National Council for Science and Technology.

Kerle, C. 2007. "International IP Protection for GMO: A Biotech Odyssey." *Columbia Science and Technology Law Review* 8.

Kikulwe, E. M., J. Wesseler, and J. B. Falck-Zepeda. 2011. "Attitudes, Perceptions, and Trust: Insights from a Consumer Survey Regarding Genetically Modified Banana in Uganda." *Appetite* 57: 401–413.

Kikulwe, E., E. Birol, J. Falck-Zepeda, and J. Wesseler. 2010. "Rural Consumers' Preferences for Banana Attributes in Uganda: Is There a Market for GM Staples?" In *Choice Experiments in Developing Countries: Implementation, Challenges, and Policy Implications,* edited by J. W. Bennett and E. Birol, 278–296. Cheltenham, UK: Edward Elgar.

Kikulwe, E. M., E. Birol, J. Wesseler, and J. Falck-Zepeda. 2011. "A Latent Class Approach to Investigating Demand for Genetically Modified Banana in Uganda." *Agricultural Economics* 42 (5): 547–560.

Kimani, V., and G. Gruère. 2010. "Implications of Import Regulations and Information Requirements under the Cartagena Protocol on Biosafety for GM Commodities in Kenya." *AgBioForum* 13 (3): 222–241.

Kimenju, S., and H. De Groote. 2008. "Consumer Willingness to Pay for Genetically Modified Food in Kenya." *Agricultural Economics* 38 (1): 35–46.

Kimenju, S., H. De Groote, C. Bett, and J. Wanyama. 2011. "Farmers, Consumers, and Gatekeepers and Their Attitudes towards Biotechnology." *African Journal of Biotechnology* 10 (23): 4767–4776.

Kirsten, J., and M. Gouse. 2003. "The Adoption and Impact of Agricultural Biotechnology in South Africa." In *The Economic and Environmental Impacts of Agbiotech: A Global Perspective,* edited by N. Kalaitzandonakes, 243–260. New York: Kluwer Academic / Plenum.

Kushwaha, S., A. S. Musa, J. Lowenberg-DeBoer, and J. Fulton. 2008. "Consumer Acceptance of Genetically Modified (GM) Cowpeas in Sub-Sahara Africa." *Journal of International Food and Agribusiness Marketing* 20 (4): 7–23.

Langyintuo, A. S., and J. Lowenberg-DeBoer. 2006. "Potential Regional Trade Implications of Adopting Bt Cowpea in West and Central Africa." *AgBioForum* 9 (2): 111–120.

Langyintuo, A. S., W. Mwangi, A. O. Diallo, J. MacRobert, J. Dixon, and M. Banziger. 2008. *An Analysis of the Bottlenecks Affecting the Production and Deployment of Maize Seed in Eastern and Southern Africa.* Harare, Zimbabwe: CIMMYT (International Maize and Wheat Improvement Center).

Lapan, H. E., and Moschini, G. 2004. "Innovation and Trade with Endogenous Market Failure: The Case of Genetically Modified Products." *American Journal of Agricultural Economics* 86: 634–648.

MAGRAMA (Spanish Ministry of Food, Agriculture, and Environment). 2014. *Encuesta sobre Superficies y Rendimientos Cultivos (ESYRCE).* Accessed May 6, 2014. www.magrama.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/.

Makinde, D., L. Mumba, and A. Ambali. 2009. "Status of Biotechnology in Africa: Challenges and Opportunities." *Asian Biotechnology and Development Review* 11 (3): 1–10.

Masum, H., J. Chakma, K. Simiyu, W. Ronoh, A. S. Daar, and P. A. Singer. 2010. "Venture Funding for Science-Based African Health Innovation." *BMC International Health and Human Rights* 10 (Suppl. 1): S12. www.biomedcentral.com/1472-698X/10/S1/S12.

Mayet, M. 2003. "Why Africa Should Adopt the OAU African Model Law on Safety in Biotechnology." Accessed May 6, 2014. www.glow-boell.de/media/de/txt_rubrik_5/SuS_Mayet_CommentBiosafetyModelLaw.pdf.

McGloughlin, M. 1999. "Ten Reasons Why Biotechnology Will Be Important to the Developing World." *AgBioForum* 2 (3–4): 163–174.

Montpellier Panel Report. 2010. *Africa and Europe: Partnerships for Agricultural Development.* London: Imperial College.

Morris, E. J. 2011. "Modern Biotechnology: Potential Contribution and Challenges for Sustainable Food Production in Sub-Saharan Africa." *Sustainability* 3: 809–822.

Morris, M., and D. Hoisington. 2000. "Bringing the Benefits of Biotechnology to the Poor: The Role of the CGIAR Centers." In *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor,* edited by M. Qaim, A. F. Krattiger, and J. von Braun, 327–355. Boston: Kluwer Academic.

Morse, S., R. Bennett, and Y. Ismael. 2006. "Environmental Impact of Genetically Modified Cotton in South Africa." *Agriculture Ecosystems and Environment* 117: 277–289.

Msangi, S., and M. W. Rosegrant. 2011. "World Agriculture in a Dynamically Changing Environment: IFPRI's Long-Term Outlook for Food and Agriculture." In *Looking Ahead in World Agriculture: Perspectives to 2050,* edited by P. Conforti, chap. 2. New York: Food and Agriculture Organization of the United Nations. www.fao.org/docrep/014/i2280e/i2280e02.pdf.

Mugabe, J. 2002. *Biotechnology in Sub-Saharan Africa: Towards a Policy Research Agenda.* ATPS Special Series Paper 3. Nairobi: Africa Technology Policy Studies Network.

———. 2003. "Biotechnology and Sustainable Development in Africa: Towards Regional Consensus and Common Strategy." Paper prepared for the First NEPAD Ministerial Conference on Science and Technology, Johannesburg, South Africa, November 7.

Mulder, M. 2004. National Biotech Survey 2003: eGoLi Bio: Life Sciences Incubator. Accessed May 1, 2014. http://www.oecd.org/science/biotech/36036991.pdf.

Munkvold, G., R. L. Hellmich, and L. G. Rice. 1999. "Comparisons of Fumonisin Concentrations in Kernels of Transgenic Bt Maize Hybrids and Nontransgenic Hybrids." *Plant Disease* 83: 130–138.

Muraguri, L. 2010. "Unplugged! An Analysis of Agricultural Biotechnology PPPs in Kenya." *Journal of International Development* 22: 289–307.

Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. B. Sulser, C. Ringler, S. Msangi, and L. You. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options.* Washington, DC: International Food Policy Research Institute.

New Alliance (New Alliance for Food Security and Nutrition). 2013. "2013 Progress Report Summary." Accessed May 2, 2014. www.gov.uk/government/uploads/system/uploads/attachment_data/file/208284/New-Alliance-Progress-Report-May2013.pdf.

NRC (National Research Council). 2010. *Impact of Genetically Engineered Crops on Farm Sustainability in the United States.* Washington, DC: National Academies Press. www.nap.edu/openbook.php?record_id=12804&page=R1.

Okusu, H. 2009. "Biotechnology Research in the CGIAR: An Overview." *AgBioForum* 12 (1): 70–77. www.agbioforum.org/v12n1/v12n1a07-okusu.pdf.

Paarlberg, R. 2001. *The Politics of Precaution: Genetically Modified Crops in Developing Countries.* Baltimore: Johns Hopkins University Press.

———. 2006. "Are Genetically Modified (GM) Crops a Commercial Risk for Africa?" *International Journal of Technology and Globalisation* 2 (1–2): 81–92.

———. 2008. *Starved for Science: How Biotechnology Is Being Kept Out of Africa.* Cambridge, MA, US: Harvard University Press.

Paarlberg, R., D. Wafula, I. Minde, and J. Wakhungu. 2006. *Commercial Export Risks from Approval of Genetically Modified (GM) Crops in the COMESA/ASARECA Region.* Nairobi: African Centre for Technology Studies Press.

Palm, C., P. Sanchez, S. Ahamed, and A. Awiti. 2007. "Soils: A Contemporary Perspective." *Annual Review of Environment and Resources* 32: 99–129.

Pardey, P. G., B. D. Wright, C. Nottenburg, E. Binenbaum, and P. Zambrano. 2003. *Intellectual Property and Developing Countries: Freedom to Operate in Agricultural Biotechnology.* IFPRI Research Brief 3. Washington, DC: International Food Policy Research Institute. www.ifpri.org/sites/default/files/publications/biotechbr3.pdf.

Pingali, P. 2010. "Agriculture Renaissance: Making 'Agriculture for Development' Work in the 21st Century." In *Handbook of Agricultural Economics,* edited by R. Evenson and P. Pingali, vol. 4, 3867–3894. London: Elsevier.

Pingali, P., and G. Traxler. 2002. "Changing Locus of Agricultural Research: Will the Poor Benefit from Biotechnology and Privatization Trends?" *Food Policy* 27 (2002): 223–238.

Pray, C. E., and A. Naseem. 2007. "Supplying Plant Biotechnology to the Poor: Opportunities and Constraints." *Journal of Development Studies* 43 (1): 192–217.

Pray, C. E., K. O. Fuglie, and D.K.N. Johnson. 2007. "Private Agricultural Research." In *Handbook of Agricultural Economics,* edited by R. Evenson and P. Pingali, vol. 3, 2605–2640. London: Elsevier.

Qaim, M. 2001. "A Prospective Evaluation of Biotechnology in Semi-subsistence Agriculture." *Agricultural Economics* 25: 165–175.

Romeis, J., D. Bartsch, F. Bigler, M. P. Candolfi, M.M.C. Gielkens, S. E. Hartley, R. L. Hellmich, J. E. Huesing, P. C. Jepson, R. Layton, H. Quemada, A. Raybould, R. I. Rose, J. Schiemann, M. K. Sears, A. M. Shelton, J. Sweet, Z. Vaituzis, and J. D. Wolt. 2008. "Assessment of Risk of Insect-Resistant Transgenic Crops to Nontarget Arthropods." *Nature Biotech* 26 (2): 203–208.

Rosegrant, M., J. Koo, Nicola Cenacchi, Claudia Ringler, Richard Robertson, Myles Fisher, Cindy Cox, Karen Garrett, Nicostrato D. Perez, and Pascale Sabbagh. 2014. *Food Security in a World of Natural Resource Scarcity: The Role of Agricultural Technologies.* Washington, DC: International Food Policy Research Institute.

Sanvido, O., J. Romeis, and F. Bigler. 2007. "Ecological Impacts of Genetically Modified Crops: Ten Years of Field Research and Commercial Cultivation." *Advances in Biochemical Engineering/Biotechnology* 107: 235–278.

Schiffer, E., and D. Waale. 2008. *Tracing Power and Influence in Networks: Net-Map as a Tool for Research and Strategic Network Planning.* IFPRI Discussion Paper 772. Washington, DC: International Food Policy Research Institute.

Shankar, B., and C. Thirtle. 2005. "Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case." *Journal of Agricultural Economics* 56: 97–116.

Shephard, G. S. 2003. "Aflatoxin and Food Safety: Recent African Perspectives." *Toxin Reviews* 22 (2–3): 267–286.

Sithole-Niang, I., J. Cohen, and P. Zambrano. 2004. "Putting GM Technologies to Work: Public Research Pipelines in Selected African Countries." *African Journal of Biotechnology* 3 (11): 564–571.

Smale, M., P. Zambrano, G. Gruère, J. Falck-Zepeda, I. Matuschke, D. Horna, L. Nagarajan, I. Yerramareddy, and H. Jones. 2009. *Measuring the Economic Impacts of Transgenic Crops in Developing Agriculture during the First Decade: Approaches, Findings, and Future Directions.* IFPRI Food Policy Review 10. Washington, DC: International Food Policy Research Institute.

Smyth, S., and P.W.P. Phillips. 2002. "Production Differentiation Alternatives: Identity Preservation, Segregation, and Traceability." *AgBioForum* 5: 30–42.

Sperling, L. 2010. "Understanding and Strengthening Informal Seed Markets." *Experimental Agriculture* 46 (2): 119–136.

Spielman, D. J. 2006. "Pro-poor Agricultural Biotechnology: Can the International Research System Deliver the Goods?" *Food Policy* 32 (2): 189–204.

Spielman, D., and K. Grebmer. 2006. "Public-Private Partnerships in International Agricultural Research: An Analysis of Constraints." *Journal of Technology Transfer* 31 (1): 291–300.

Subramanian, A., and M. Qaim. 2009. "Village-wide Effects of Agricultural Biotechnology: The Case of Bt Cotton in India." *World Development* 37: 256–267.

———. 2010. "The Impact of Bt Cotton on Poor Households in Rural India." *Journal of Development Studies* 46 (2): 295–311.

Tait, J., and G. Barker. 2011. "Global Food Security and the Governance of Modern Biotechnology." *EMBO* 12 (8): 763–768.

Tanzania (United Republic of Tanzania). 2010. *National Biotechnology Policy.* Dar Es Salaam, Tanzania: Ministry of Communication, Science and Technology. www.tzonline.org/pdf/Biotecchnology_Policy_WEBB1.pdf.

Thirtle, C., L. Beyers, Y. Ismael, and J. Piesse. 2003. "Can GM Technologies Help the Poor?: The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal." *World Development* 31 (4): 717–732.

Thomson, J. A., D. N. Shepherd, and H. D. Mignouna. 2010. "Developments in Agricultural Biotechnology in Sub-Saharan Africa." *AgBioForum* 13 (4): 314–319.

Thorpe, P. n.d. "Study on the Implementation of the TRIPS Agreement by Developing Countries." Study Paper 7. Commission on Intellectual Property Rights, World Health Organization, Geneva. www.iprcommission.org/papers/pdfs/study_papers/sp7_thorpe_study.pdf.

Trigo, E. 2003. "Developing and Accessing Agricultural Biotechnology in Emerging Countries: Policy Options in Different Country Contexts." In *Accessing Agricultural Biotechnology in Emerging Economies: Proceedings of the OECD Global Forum on Knowledge Economy,* Paris, November 18–19, 2002.

Tripp, R. 2001. "Can Biotechnology Reach the Poor?: The Adequacy of Information and Seed Delivery." *Food Policy* 26: 249–264.

———, ed. 2009. *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions, and Resource-Poor Farmers.* Routledge Explorations in Environmental Economics 19. London: Routledge.

UN (United Nations). 2009. *World Population Prospects: The 2008 Revision.* New York: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

UNEP (United Nations Environmental Programme). 2006. *Africa Environment Outlook 2—Our Environment, Our Wealth* (AEO-2). Nairobi. www.unep.org/dewa/Africa/publications/AEO-2/content/154.htm.

Unnevehr, L., and D. Grace, ed. 2013. *Aflatoxins: Finding Solutions for Improved Food Safety.* 2020 Vision Focus 20. Washington, DC: International Food Policy Research Institute.

USDA (United States Department of Agriculture). 2013. "Acreage." Accessed June 11, 2014. http://usda01.library.cornell.edu/usda/current/Acre/Acre-06-28-2013.pdf.

USDA-FAS (US Department of Agriculture–Foreign Agricultural Service). 2013. *2013 Francophone West Africa Biotechnology Report.* 2013 GAIN report. Accessed May 2, 2014. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Agricultural%20Biotechnology%20Annual_Dakar_Senegal_7-29-2013.pdf.

Van Mele, P., J. W. Bently, and R. G. Guei. 2011. *African Seed Enterprises: Sowing the Seeds of Food Security.* Wallingford, UK: CAB International.

Verwer, C. C., J. Buiteveld, H. P. Koelewijn, W. Tolkamp, S.M.G. de Vries, and P. J. van der Meer. 2010. *Genetically Modified Trees: Status, Trends, and Potential Environmental Risks.* Alterra Report 2039. Wageningen, the Netherlands: Alterra.

Viljoen, B., K. Dajee, and G. M. Botha. 2006. "Detection of GMO in Food Products in South Africa: Implications of GMO Labeling." *African Journal of Biotechnology* 5: 73–82.

Vitale, J., T. Boyer, R. Raine, and J. H. Sanders. 2007. "The Economic Impacts of Introducing Bt Technology in Smallholder Cotton Production Systems of West Africa: A Case Study from Mali." *AgBioForum* 10: 71–84.

Vitale, J., H. Glick, J. Greenplate, and O. Traore. 2008. "The Economic Impacts of Second Generation Bt Cotton in West Africa: Empirical Evidence from Burkina Faso." *International Journal of Biotechnology* 10 (2–3): 167–183.

Vitale, J. D., G. Vognan, M. Ouattarra, and O. Traore. 2010. "The Commercial Application of GMO Crops in Africa: Burkina Faso's Decade of Experience with Bt Cotton." *AgBioForum* 13 (4): 320–332.

Wafula, D., M. Waithaka, J. Komen, and M. Karembu. 2012. "Biosafety Legislation and Biotechnology Development Gains Momentum in Africa." *Journal of GM Crops: Special Issue on Biosafety Regulation* 3(1): 72–77.

Wakhungu, J. 2009. "Governing Agricultural Biotechnology in Africa." In *Golden Rice and Other Biofortified Food Crops for Developing Countries: Challenges and Potential,* edited by A. Lindqvist and T. Verba, 83–86. Edition 1000. Stockholm: Royal Swedish Academy of Agriculture and Forestry.

Waruru, M. 2011. "Kenya's Scientists Urged to Engage in GM Debate." SciDev.Net, September 16. Accessed May 6, 2014. www.scidev.net/en/agriculture-and-environment/gm-crops/news/kenya-s-scientists-urged-to-engage-in-gm-debate.html.

Welcome Europe. 2014. "Food Security Thematic Programme (FSTP)." Accessed May 6, 2014. www.welcomeurope.com/european-funds/food-security-thematic-programme-fstp-602+502.html.

Willer, H., and M. Yussefi. 2005. *The World of Organic Agriculture: Statistics and Emerging Trends, 2006.* Bonn: International Federation of Organic Agriculture Movements; Frick, Switzerland: Research Institute of Organic Agriculture.

World Bank. 2011. World Development Indicators. Online database. Accessed October 2011. http://data.worldbank.org/data-catalog/world-development-indicators.

———. 2014. World Development Indicators. Online database. Accessed February 2014. http://databank.worldbank.org/data/views/variableSelection/selectvariables.aspx?source=world-development-indicators.

Wu, F. 2006a. "An Analysis of Bt Corn's Benefits and Risks for National and Regional Policymakers Considering Bt Corn Adoption." *International Journal of Technology and Globalisation* 2 (1–2): 115–136.

———. 2006b. "Mycotoxin Reduction in Bt Corn: Potential Economic, Health, and Regulatory Impacts." *Transgenic Research* 15: 277–289.

Wu, F., J. D. Miller, and E. A. Casman. 2004. "Bt Corn and Mycotoxin Reduction: An Economic Perspective." *Journal of Toxicology* 23 (2–3): 397–424.

Wu, F., C. Narrod, M. Tiongco, and Y. Liu. 2011. *The Health Economics of Aflatoxin: Global Burden of Disease.* Aflacontrol Working Paper 4. Washington, DC: International Food Policy Research Institute.

Zambia (Republic of Zambia). 2007. *Biosafety Bill.* Accessed May 2, 2014. www.zambialii.org/files/zm/legislation/act/2007/10/baa2007215.pdf.

Zambrano, P., J. H. Maldonado, S. L. Mendoza, L. Ruiz, L. A. Fonseca, and I. Cardona. 2011. *Women Cotton Farmers, Their Perceptions and Experiences with Transgenic Varieties: A Case Study for Colombia.* IFPRI Discussion Paper 1118. Washington, DC: International Food Policy Research Institute.

Zarrilli, S. 2005. *International Trade in GMOs and GM Products: National and Multilateral Legal Frameworks.* UNCTAD Policy Issues in International Trade and Commodities Study Series 29. New York and Geneva: United Nations Conference on Trade and Development. http://unctad.org/en/Docs/itcdtab30_en.pdf.

Zerbe, N. 2004. "Feeding the Famine? American Food Aid and the GMO Debate in Southern Africa." *Food Policy* 29 (6): 593–608.

Zomer, R. J., D. A. Bossio, A. Trabucco, L. Yuanjie, D. C. Gupta, and V. P. Singh. 2007. *Trees and Water: Smallholder Agroforestry on Irrigated Lands in Northern India.* Research Report 122. Colombo, Sri Lanka: International Water Management Institute.

Zomer, R. J., A. Trabucco, D. A. Bossio, and L. V. Verchot. 2008. "Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation." *Agriculture, Ecosystems and Environment* 126 (1–2): 67–80.

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Jeff Stein (jstein@danforthcenter.org) is a PBS biosafety adviser and provides biosafety and regulatory support for public-sector research programs and regulators in developing countries in Africa and Asia. In this role he consults with regulatory agencies as they draft their biosafety-related legislation, enabling regulations, and guidance documents. He shares his more than 25 years of global biosafety experience with national agricultural research centers and academic institutions to build in-country scientific capacity to set guidelines for confined field trials and comply with those guidelines. In addition to working with the PBS, Stein is a biosafety adviser associated with the Donald Danforth Plant Science Center. Prior to this, he served as director of regulatory affairs for a private company. He works mostly in Ghana, Kenya, Indonesia, the Philippines, Uganda, and Vietnam; has served on numerous domestic and international committees that set standards for managing crops derived through biotechnology; and has overseen stewardship activities. He enjoys the opportunity of working with experienced scientists in developing countries to address the political and scientific challenges to the adoption of a technology that can reduce malnutrition and disease as well as improve the economic well-being of millions of people in these countries.

David Wafula (wafuladavid@yahoo.com) was the PBS Kenya coordinator until 2013. His main areas of professional interest are science and technology policy, and he maintains a keen interest in agricultural biotechnology, biosafety, trade, food security, and regional harmonization issues. He has published widely on these issues and worked closely with regional bodies including the Association for Strengthening Agricultural Research in Eastern and Central Africa and the Common Market for Eastern and Southern Africa.