Research Paper

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Energy, Environment and Resources | July 2014

On Trial: Agricultural Biotechnology in Africa

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Summary

Increasing agricultural productivity and adapting farming to climate change are central to Africa's development prospects. There are important opportunities to enhance yields and increase resilience through the adoption of improved crop varieties. In some cases, biotechnology, and in particular genetic modification (GM), offers advantages over conventional plant-breeding approaches. Accordingly there are a various projects under way to develop new GM varieties for African farmers, ranging from drought-resistant maize to varieties of cassava, banana, sorghum, cowpea and sweet potato with resistance to pests and disease.

In addition to government funds, these projects have also attracted the support of influential donor agencies and philanthropic foundations. However, despite the expenditure of considerable resources, the potential of GM in Africa is not being realized. So far no GM trait developed for African farmers has been put to use.

Multiple barriers inhibit the development and adoption of pro-poor GM varieties in Africa. On the demand side, farmers may be reluctant to adopt GM varieties owing to a lack of export opportunities and distrust of the technology among local consumers. Farmers may also be concerned about exploitation by transnational seed companies (despite the fact that development of new GM technologies in Africa is dominated by the public sector). On the supply side, donor funding struggles to match the long timescales of research and development, while incentives among research scientists may be poorly aligned with farmer outcomes. Non-existent, poorly functioning or overly punitive regulatory regimes discourage investment.

The most important barriers – such as regulatory constraints, consumer distrust and weak farmer demand – must be understood in the context of wider social and political dynamics surrounding GM, typified by misinformation, polarized public discourse, and dysfunctional and opportunistic politics. The result is most GM projects becoming 'stuck' at the field trial stage without ever progressing to release. This 'convenient deadlock' of continual field trials allows governments to manage political risks by effectively balancing the demands of pro-GM and anti-GM lobbies – proponents of GM have a pipeline of technologies, while opponents are appeased by the failure of any to gain approval. The disabling socio-political environment for GM development in Africa greatly reduces the efficacy of investment in this technology.

This has two important implications. First, technology development needs to be located within a wider project of transformation that engages key actors – most notably politicians, policy-makers and farmers – as stakeholders from the outset, and includes strategies to address multiple demand- and supply-side barriers. Second, successful adoption is more likely in countries with less disabling political conditions, characterized by lower levels of consumer distrust and opposition, genuine farmer demand and demonstrable commitment from government. Focusing efforts and resources on a small number of 'best bet' countries will also allow donors and technology providers to support more ambitious, transformational projects led by national governments.

Introduction

Agriculture is fundamental to development sub-Saharan Africa (hereafter 'Africa'). Poverty is concentrated: three-quarters of those in extreme poverty, with incomes less than $1.25 a day, live in rural areas.[1] Almost two-thirds of people work in the agricultural sector, which accounts for a third of GDP and half of export earnings.[2]

But agricultural development in Africa is a complex challenge. Problems include a reliance on rain-fed cropping systems, low soil fertility, weak land-tenure systems, a lack of access to finance, and a lack of transport and market infrastructure, among other things.[3] Together, these present a pre-existing 'development deficit' that increases the vulnerability of African agriculture to climate change. Africa's agricultural development is in a race against time to eliminate this deficit while simultaneously adapting to a rapidly changing climate.

The stakes are extraordinarily high. Climate change is expected to lead to significant reductions in African crop yields,[4] threatening the livelihoods of millions of poor subsistence farmers and agricultural workers. On the other hand, closing the development deficit and providing farmers with access to the investment, technologies and knowledge they need to adapt to climate change could transform their development prospects. Increasing farm productivity is a priority. African yields have stagnated at levels well below global averages. Narrowing the yield gap could increase farm incomes and food availability within Africa, with beneficial impacts on hunger and poverty.

Improving farmers' access to technology is central to meeting the double challenge of closing the development deficit and adapting to climate change. The Green Revolution is usually offered as the paradigmatic example of technology-driven agricultural transformation. This was essentially a succession of research-led initiatives resulting in the distribution of new high-yielding seed varieties, irrigation infrastructure and fertilizers to farmers throughout Asia and Latin America during the mid-twentieth century. The results for farm productivity were spectacular. Despite rapid population growth, per capita cereal output has increased by 44 per cent in Asia and 48 per cent in South America since 1960. Meanwhile, in Africa it has declined by 13 per cent.[5]

Unsurprisingly, attention is now focused on the potential of modern seed varieties for African agriculture. African farmers are heavily reliant on unimproved traditional or landrace varieties.[6] A lack of commercial incentives means many of the subsistence crops grown by smallholder farmers – such as

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1 International Fund for Agricultural Development (IFAD) (2010), 'Rural Poverty Report 2011: Facts & Figures'.

2 Organization for Economic Cooperation and Development (OECD) (2009), 'Growing Prosperity: Agriculture, Economic Renewal and Development'.

3 United Nations Development Programme (UNDP) (2012), *Africa: Human Development Report 2012: Towards a Food Secure Future*.

4 World Bank (2009), *World Development Report 2010: Development and Climate Change*.

5 UNDP, *Africa*.

6 Data on adoption of modern varieties in sub-Saharan Africa are scarce. Preliminary estimates for 10 key staples indicate that modern varieties account for 10 to 40 per cent of planted area, the notable exceptions being maize and potatoes with adoption rates of 67 and 59 per cent respectively. See Alene, A. et al. (2011), 'Measuring the Effectiveness of Agricultural R&D in Sub-Saharan Africa from the Perspectives of Varietal Output and Adoption: Initial Results from the Diffusion of Improved Varieties in Africa Project', paper prepared for the ASTI/IFPRI-FARA Conference, Accra, 5–7 December, 2011.

cassava, bananas such as matoke and plantains, teff and millet – receive relatively little attention from researchers. But higher yields among these so-called 'orphan crops' could generate significant benefits for livelihoods and food security. In addition to enhanced yields, other important objectives for plant breeders – in subsistence and cash crops alike – include disease resistance, pest resistance, biofortification, and tolerance to drought, salinity, heat and waterlogging (the last four being particularly important for adaptation to climate change).

The technologies and techniques available to plant breeders have increased significantly since the Green Revolution, most notably in the area of biotechnology. Although biotechnology – and in particular one application of it, genetic modification (GM) – remains controversial, it is regarded as an important opportunity by an array of influential donors, foundations, scientists and agricultural development experts. Nevertheless, adoption of biotechnology in Africa has been limited. Only three sub-Saharan countries – South Africa, Burkina Faso and Sudan – have commercialized GM varieties, and these were originally developed for American rather than African farmers: Bt cotton and maize, and glyphosate resistant maize and soybean.[7]

Why then, given its apparent potential and the support of an influential constituency within the development community, has agricultural biotechnology failed to make more of an impact in Africa? This paper explores this question, drawing on the results of an expert roundtable at Chatham House, interviews with donors, policy-makers, scientists, farmers and representatives from non-governmental organizations, and fieldwork in Uganda. In so doing, it does not seek to make a case either for or against biotechnology or GM: there is a wealth of existing literature already doing so. What concerns us here is the success of endeavours to develop and disseminate these technologies within Africa. This is an important question given the extent of efforts and resources devoted to this agenda in recent years.

The paper begins with a short overview of debates about biotechnology before summarizing barriers to its development and adoption in Africa. It then considers how these barriers are influenced by wider political and institutional factors before finishing with some possible implications for donors, national governments, development organizations and scientific researchers.

Biotechnology and GM

Biotechnology is broadly defined by the Convention on Biological Diversity as 'any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use'. Biotechnologies commonly used for plant breeding include:

- *Marker assisted selection* (MAS), in which breeders use DNA 'markers' to identify genes associated with certain traits, allowing progeny to be screened for desired genes. This can reduce breeding times significantly, as the conventional process of screening for traits (as opposed to genes) takes longer.

[7] North of the Sahara, Egypt has commercialized Bt maize.

- *Plant tissue culture*, through which plant cells are grown in laboratory conditions. This offers a number of opportunities including reduced contamination of plants, rapid propagation, and cloning of clean planting material.

- *Genetic modification* (GM), through which a gene from one organism is transferred to another. The inserted gene may be from the same species (cisgenics) or from another species (transgenics).

GM arguably presents the greatest opportunities to plant breeders. It can reduce breeding times by avoiding the need to cross varieties and screen progeny. Cisgenics can avoid the problem of 'linkage drag', which occurs in conventional breeding when deleterious traits are genetically linked to desired traits. Transgenics allows for the introduction of traits unavailable from within the species genome. It therefore offers particular opportunities for many African staple crops with shallow gene pools.

It is also argued that GM poses greater risks. Indeed those opposed to GM technologies have done so very effectively. In assessing risk, however, it is important to consider whether this relates to GM technology *per se*, to the trait itself, or to the trait's interaction with wider contextual factors such as ecosystems or agronomic practices. For example, a risk related to the release of Bt varieties, which produce natural insecticides, is that because they are expressed continuously and throughout the crop cycle, they may inadvertently affect non-target insects and disrupt the ecosystem more than conventional pesticide spraying. But the risk is associated with the trait rather than the method of plant breeding used to introduce it; conventional plant breeding has also been used to develop insect resistance.

Traits introduced through GM have resulted in adverse environmental consequences in some instances. Most notably, the widespread planting of crops engineered to tolerate the herbicide glyphosate has led to the emergence of glyphosate-resistant weeds. However, these 'superweeds' are not a consequence of genetic modification itself, but of the widespread change in farming practices that followed the introduction of the (transgenic) glyphosate-resistant trait. The adoption of the herbicide-resistant crop facilitated the profligate and exclusive application of glyphosate and spurred the evolution of resistant weeds. Prior to this, farmers had slowed the development of resistance by using multiple different herbicides.[8]

Another concern is the risk of gene flow, whereby modified genes are incorporated into related crops or weedy relatives through pollination. Glyphosate resistance has also emerged through this channel: in Canada, a glyphosate tolerance gene flowed from GM canola (*Brassica napus*) into a weedy relative (*Brassica rapa*).[9] However, the risk of gene flow is equally relevant with conventional breeding: there is no evidence that transgenes move between crops more easily than endogenous genes.[10] This is not to

[8] To survive herbicide application and pass on resistance to its progeny, a weed must undergo a genetic mutation bestowing resistance. Such mutations are essentially random and occur with small probability. However given sufficient time and exposure to the herbicide, such a mutation will inevitably occur and be selected for. Using multiple herbicides slows this process: should random resistance to one herbicide emerge, the plant will still be killed by the application of the other herbicides, meaning the resistance trait will not be selected for. Selection requires multiple simultaneous mutations bestowing resistance to all herbicides at once, with a correspondingly tiny cumulative probability.

[9] Conway, G. (2013), *One Billion Hungry: Can We Feed the World?* (Cornell University Press).

[10] Royal Society (2009), 'Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture' (London: The Royal Society).

say that the risk of gene flow should not be assessed and managed, only to acknowledge that the risk occurs whenever a new variety is introduced, irrespective of the plant-breeding technique used. Ultimately, the extent of gene-flow risk relates to the nature of the trait and the probability of flow, neither of which depends upon the method of plant breeding.[11]

The discussion above is concerned with the risks arising from desired traits. However, the aim of plant breeding is not only to introduce desired traits, but to do so while avoiding the introduction of undesired traits. With respect to this second objective, GM may be riskier. This is because unintended genetic outcomes may be more likely with 'first generation' GM techniques than with traditional cross-breeding.[12] The vast majority of unintended genetic outcomes will be harmless but some may not be. Arguably the gravest risk is an unintended genetic outcome resulting in a trait that is harmful to human health, though it is important to note that no adverse consequences for human or animal health from consuming GM foods have been recorded.[13] Advances in GM technologies are expected to almost eliminate these risks in the future. New 'second generation' GM techniques allow much greater precision. Scientists can now use particular enzymes to effectively edit chromosomes at specific loci, thus minimizing the risk of unintentionally disrupting the genome.

It is also noteworthy that while first-generation GM may be more likely to generate unintended genetic outcomes than cross-breeding, it is not the most risky plant-breeding technique. The risk of unintended genetic outcomes is actually greatest with the conventional breeding approach of mutagenesis,[14] a technique that induces random mutations by exposing seeds to radiation or chemicals and then selects progeny with desirable traits. The UN Food and Agriculture Organization and International Atomic Energy Agency maintain a database of released mutant cultivars, which currently lists 3,218 such varieties including 274 of wheat, 824 of rice, 96 of maize and 170 of soybean.[15] The key to avoiding release of crops with unintended genetic outcomes lies less in the method of generating new plants for selection than in the rigour with which candidate plants are screened during breeding and in subsequent processes of regulatory testing.

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[11] The probability of flow is largely determined by the crop-breeding system (inbreeding or outbreeding) and the relative density of source pollen plants to recipient plants. Ibid.

[12] See National Research Council (2004), *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects* (Washington, DC: National Academies Press). The authors ranked different plant breeding approaches according to the likelihood of unintended genetic effects. All else being equal, GM techniques were found to have greater likelihood of unintended genetic effects than conventional plant breeding.

[13] See, for example, Lemaux, P. (2008), 'Genetically Engineered Plants and Foods: A Scientist's Analysis of the Issues (Part I), *Annual Review of Plant Biology*, Vol. 59; and European Academies Science Advisory Council (EASAC) (2013), 'Planting the Future: Opportunities and Challenges for Using Crop Genetic Improvement Technologies for Sustainable Agriculture'.

[14] National Research Council (2004), *Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects* (Washington, DC: National Academies Press).

[15] FAO and IAEA Mutant Variety Database, http://mvgs.iaea.org/Search.aspx

Biosafety and regulation

Assessing and managing the risks from new varieties – whether from unintended/undesired traits or intended/desired traits – is clearly important. Biotechnology is subject to regulation under national biosafety regimes. Following strict testing in the laboratory, greenhouse and field, GM varieties must undergo a process of regulatory approval and registration, which typically lasts about five years.[16] Different governments have taken different approaches to biosafety regulation. For example, in the EU an emphasis on the precautionary principle means that GM crops are largely absent from European fields. The US system weighs risk against benefit, with the result that GM acreage – in major crops such as soybean, maize, canola and cotton – is significant.

New varieties produced through other forms of plant breeding – including mutagenesis – are subject to less stringent regulations. Registering a non-GM variety typically takes —one to two years compared with four years or more for a GM variety, for example. The binary differentiation made between GM and non-GM crops in current regulatory approaches therefore appears imperfect. As well as resulting in the anomalous treatment of mutants, this also means that a trait expressed in a conventionally bred variety would be treated very differently from the same trait expressed in a GM variety, despite the fact that the risks are very similar.

Criticisms of regulatory approaches aside, the fact remains that the introduction of GM crops does require a functioning biosafety regime to assess and manage risk; for poor African governments, with relatively weak institutions, low levels of regulatory capacity and enforcement, and limited scientific expertise and financial resources, this can be a significant challenge.

GM, intellectual property and big business

In addition to potential risks to health and the environment, opponents of GM also argue that the technology naturally concentrates power and resources with large transnational companies (TNCs) that own the intellectual property (IP) associated with new technologies, allowing them to charge farmers exploitative prices for GM seeds and limit farmers' rights to save and exchange seeds.[17] TNCs could often have done more to dispel these concerns. For example in the 1990s Monsanto explored so-called 'terminator technology' – which would have produced crops with sterile seeds – as a way to prevent seed saving and exchange. However, terminator technology was never commercialized.

More fundamentally, concerns about concentration of IP and the potential for this to lead to exploitative business practices are related to the institutions that govern IP, rather than the technology itself. For example, the tension between the rights of plant breeders and those of farmers is as relevant

[16] McDougall, P. (2011), 'The cost and time involved in the discovery, development and authorization of a new plant biotechnology derived trait', Crop Life International, http://www.croplife.org/view_document.aspx?docId=3338.
[17] This tendency is exacerbated by the high regulatory costs of approving a GM variety, which only large corporations can afford. This is somewhat ironic, as more stringent regulation is something opponents of GM tend to favour.

to conventional hybrid varieties as to GM. Similarly the regular purchasing of seed and strict rules for seed stewardship are equally necessary for hybrid seeds, not only to protect IP rights, but also to preserve hybrid vigour,[18] prevent contamination of germplasm, prevent counterfeiting and ultimately manage brand risk. For example, in Uganda poor enforcement of the national seed law has resulted in significant counterfeiting of hybrid varieties and poor quality controls for the introduction of new seeds. This has undermined trust among farmers in new commercial varieties – whether from traditional or GM breeding technologies. Meanwhile reluctance among banana farmers to 'buy something we could get for free' has facilitated the spread of xanthomonas wilt via the exchange of contaminated germplasm (see Box 2). What farmers may get for free (contaminated plant cuttings) is not necessarily the same as what they can buy (clean tissue culture plantlets).

Demand-side barriers

A variety of barriers can dampen demand among African farmers for new technologies.

General challenges

Biotechnology aside, technology adoption in African agriculture is far from straightforward. In general the uptake of new technologies among poor farmers is hampered by a wider range of barriers, including:

- A lack of knowledge, information and training about technologies and how to use them;
- A lack of financial services to bridge the gap between up-front technology costs and deferred technology derived gains;
- Poor connectivity to markets, for inputs and crops;
- A lack of infrastructure for roads, storage or irrigation;
- Inappropriate institutions – for example, weak land-tenure arrangements may discourage farmer investment; and
- A variety of locally specific social or cultural factors – for example, relating to gender-based norms.

In this context, adopting a new technology is a risky proposition for poor farmers with little in the way of resources to spend on the technology or fall back on if the technology fails. Investing in a new technology may quite literally involve 'betting the farm'. Market connectivity is key – for example, a technology that increases productivity in the context of small and fragmented crop markets could see

[18] Hybrid vigour is the increase in traits such as size, growth rate, and yield of a hybrid plant over its parents. Vigour typically deteriorates if hybrid lines are then mated together. Therefore to maintain vigour, parental lines must be maintained and crossed, and new hybrid seeds purchased, for each new crop.

farmgate prices fall and the technology abandoned. Increasingly, development practitioners are taking a holistic approach, accompanying technology provision with multiple interventions to encourage investment and create an enabling environment for adoption.

GM-specific challenges

In addition to these general demand-side barriers, biotechnology faces its own particular challenges. African farmers do not see an attractive market opportunity for GM food at home or abroad. Anti-GM campaigns mean that anxieties about the risks of consuming GM food are common in many African markets. The EU, the largest market for Africa's agricultural exports, accepts GM crops as animal feed but not for consumer markets. European labelling requirements for GM ingredients can present a barrier to entry for poor farmers seeking to enter EU supply chains.

In addition to concerns they may not be able to sell GM crops, farmers may have further concerns about the terms on which they must purchase GM seed, particularly regarding contracts that may limit their ability to save or exchange seed (see previous section – such restrictions are not unique to GM seed, but are sometimes misunderstood to be). This is a common concern among advocacy and campaign groups promoting 'food sovereignty', many of which work with farmers' organizations in Africa. During research for this paper, farmers voiced fears that use of GM varieties would erode their rights to save and exchange seed.

Supply-side barriers

On the supply side, the private sector lacks sufficient commercial incentives to develop biotechnologies for the African market, while public R&D faces a number of institutional barriers.

Private-sector constraints

The economics of GM product development present a number of challenges for businesses wishing to target African farmers. The research and development (R&D) pipeline is long, typified by high upfront costs and lengthy and expensive deregulation processes. According to one estimate, the discovery and commercialization of a typical GM trait takes 13 years and costs $136 million, with deregulation accounting for over a quarter of costs.[19] The costs of developing a commercial GM crop may actually be significantly higher, as this is increasingly likely to contain stacked or multiple traits.[20] Embarking on this process with no guarantee of a successful outcome is a risky proposition, and so the potential rewards must be significant in order to attract private R&D. However potential African markets are tiny compared with those in other regions. For example, the US seed market is estimated to be 100 times greater than Nigeria's, 800 times greater than Tanzania's and 1,200 times greater than Uganda's.[21] Not only are African markets smaller, but they are more fragmented and dispersed, significantly increasing the costs of marketing and distribution.

[19] McDougall (2011), 'The cost and time involved'.

[20] Anthony, V. and Ferroni, M. (2011), 'Agricultural Biotechnology and Smallholder Farmers in Developing Countries', *Current Opinion in Biotechnology*, Vol. 23.

[21] International Seed Federation (2013),'Estimated Market Value of the Domestic Seed Market in Selected Countries for the year 2012 (updated June 2013) 'http://www.worldseed.org/cms/medias/file/ResourceCenter/SeedStatistics/Domestic_Market_Value_2012.pdf

Consequently, the private sector has little incentive to invest in developing technologies for Africa. Instead, private capital has tended to focus on advanced agricultural markets – principally in North America and South America. This has resulted in the commercialization of two traits – Bt insect resistance and glyphosate resistance – in cash crops such as maize, soybean, canola and cotton, the released varieties of which are based on commercial hybrids that do not necessarily address the specific needs of African farmers for germplasm adapted to their particular agronomic and climatic context. And while these technologies may offer opportunities for some African farmers, GM advances in 'orphan crops' could offer wider benefits.

The lack of commercial incentives for private investment is compounded by regulatory risk. A functioning biosafety regime able to set out a predictable pathway towards commercial release is a prerequisite for private investment, yet many African countries do not have functioning biosafety regimes in place. Of 47 sub-Saharan African countries, 18 have national biosafety laws; however, in many of these countries there is a significant gap between legislation and implementation, and only seven are undertaking field trials (a further two countries are undertaking field trials in the absence of biosafety laws).[22]

National biosafety regimes are often poorly harmonized with those of neighbouring countries. This increases regulatory costs for technology providers, which must navigate multiple deregulation processes. Strict liability provisions are a common element of biosafety laws (see Box 1). These often deter technology providers, which could face considerable financial penalties in the event of contamination by, or cross-border movement of, GM seed – risks that are impossible to eliminate, particularly in situations of weak stewardship of seed distribution and use.

Biotechnology research is expensive and particularly knowledge-intensive. With low and stagnant budgets, national research institutions have struggled to fund programmes and retain scientists. In addition to a low national funding base, agricultural biotechnology R&D in the public sector faces a number of further challenges, as outlined below.

- In the absence of sufficient national resources, there may be a reliance on volatile and short-term donor funding, leading to problems should donor priorities change or particular 'big ticket' projects conclude. At typically around five years, donor funding is short-term compared with the timelines involved in developing, testing and commercializing GM technologies. This means that often only a particular stage of technology development gets funded and projects may conclude prematurely as grants expire.[23]

- Incentives for research scientists may not be aligned with outcomes for farmers. For many research scientists, 'success' is defined in terms of knowledge generation, and more concretely as publication

[22] Authors' analysis of data from African Biosafety Network of Expertise (2013), http://www.nepadbiosafety.net/subjects/biotechnology/status-of-crop-biotechnology-in-africa.
[23] For example, a review of biotechnology in four African countries concluded that 'short term funding for R&D is clearly not sustained' and identified gaps between R&D and implementation; see Black, R. et al. (2011), 'Case Studies on the Use of Biotechnologies and on Biosafety Provisions in Four African Countries', *Journal of Biotechnology*, Vol. 156.

in a peer-reviewed journal. This is essentially unrelated to whether or not the technology is successful from the point of view of African farmers, and ultimately adopted.

- Research processes are, more broadly, poorly connected to farmers. Although many research institutions are trying to address this disconnect, engaging farmer organizations in the development of technology remains a major challenge. Farmer participation over the course of the process – from identifying needs through to testing and commercialization – maximizes the chance of appropriate technologies being developed and adopted.

In combination, these factors lead to a short-term, top-down approach that places insufficient emphasis on the later stages of technology development, in particular commercialization and extension. Projects may be partial in their ambition and term, designed to generate knowledge rather than address specific farmer needs. As a result, activity has often been concentrated upstream and the commercial viability of technologies reduced.

Box 1: GM and liability

A further barrier to GM adoption in Africa that is rarely commented on in the academic literature but widely recognized among biotechnology developers is the current application of liability law in respect of GM products. In line with the Cartagena Protocol, many African countries apply strict liability conditions to GM products, meaning any party, corporate or individual, that works with GM products is liable for any loss arising from use of these products. This can include losses incurred if GM products contaminate non-GM products[a], does not require any fault to be proven and can apply despite the utmost exercise of care.[b] Thus inventors or owners of a GM technology can be deemed liable even if the technology is donated free or provided as a public good.

GM contamination of non-GM crops of both corn and rice in the United States has led to seed companies reportedly incurring costs of up to $1 billion.[c] This is therefore a serious barrier to GM technology originators or facilitators either commercializing or gifting GM technology to African countries where stringent liability laws exist, seed stewardship is weak and any countervailing commercial opportunity is low or non-existent. The situation is made harder still by the lack of coherence between the liability regimes of African countries, which often share porous borders across which GM material could easily travel unregulated. A recent major public–private partnership to produce GM pest-resistant vegetables for Africa dissolved in part as a result of concerns over uncertain and open-ended liabilities in connection with strict liability.[d] Many donor representatives interviewed for this research have cited punitive liability regimes as one of the principal challenges they face in developing pro-poor GM technologies for use in Africa.

Sources:

a Kershen, D. (2009), 'Legal Liability and Agricultural Biotechnology: Ten Questions', http://jay.law.ou.edu/faculty/kershen/articles/LegalLiabilityIssues.pdf

b Boadi, R. (2007), 'Managing Liability Associated with Genetically Modified Crops', in Krattiger, A. et al (eds.), Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices, http://www.iphandbook.org/handbook/ch14/p05/

c Schmitz, T. et al (2005), 'The Economic Impact of Starlink Corn', Agribusiness, Vol. 21 (3). And Harris, A. and Beasley, D. (2011). 'Bayer Agrees to Pay $750 Million to End Lawsuits over Gene-Modified Rice', Bloomberg News, http://www.bloomberg.com/news/2011-07-01/bayer-to-pay-750-million-to-end-lawsuits-over-genetically-modified-rice.html

d Russell, D. et al (2011), 'Progress and Challenges in the Bt Brassicas CIMBAA Public-Private Partnership', in Srinivasan, R. et al (eds.) Proceedings of the Sixth International Workshop on Management of the Diamondback Moth and Other Crucifer Insect Pests, 21-25 March 2011. Kasetsart University, Nakhon Pathom, Thailand.

Public–private partnerships

Public–private partnerships (PPPs) could provide models to overcome the respective constraints of public and private actors. The private sector can offer well-established downstream expertise in commercialization and marketing, for example, while the public sector can justify upstream R&D in technologies that may not offer significant commercial returns but do provide significant social and environmental returns. More often, however, it seems that PPPs assume a different arrangement more aligned with the corporate social responsibility agendas of private actors, in which companies donate biotechnology IP but still lack the incentives to undertake downstream activities.

Other common problems with PPPs identified by participants in the research related to the challenges of bringing two different organizations and cultures together in a long-term shared endeavour. In particular, PPPs may struggle to align public and private stakeholders behind a shared long-term vision and common objectives, and are vulnerable to a lack of staff continuity over the course of the initiative. An alternative model used successfully to develop vaccines for developing-country markets is the advanced market commitment. In this form of PPP, public funds are used to underwrite market demand for private actors, providing them with an incentive to operate along the value chain, from R&D to commercialization.

The politics of GM

Political discourses about GM have been instrumental in shaping supply-side and demand-side barriers.

Politics and regulation

The regulatory context in Africa, typified by non-existent, poorly functioning or highly restrictive biosafety regimes, presents a significant supply-side constraint to the development of biotechnologies. A lack of domestic institutional capacity is a partial explanation for this, but so are a number of wider political factors.

A highly polarized debate about GM in many African countries creates political risk for governments perceived to be pro-GM. In many countries, civil society and media campaigns against GM technologies are seen to have made politicians and policy-makers reluctant to progress biosafety legislation or take decisions towards the release of biotechnologies.[24]

Even where a functioning biosafety regime exists, regulatory decisions may still be politicized. Interviewees for this research commonly said that regulatory decisions were unpredictable and subject to political interference. In 2012, for example, in a move widely seen as a response to anti-GM campaigning, the Kenyan government announced a blanket ban on GM imports despite what many consider to be a relatively advanced biosafety regime.

[24] Interviewees for this research identified vociferous anti-GM campaigns in Kenya, Uganda and Mali. Also see Paarlberg, R. (2009), *Starved for Science: How Biotechnology Is Being Kept Out of Africa'* (Cambridge, MA: Harvard University Press); Adenle, A. et al. (2013), 'Status of Development, Regulation and Adoption of GM Agriculture in Africa: Views and Positions of Stakeholder Groups', *Food Policy*, Vol. 43.

Box 2: A poor-pro GM banana for Uganda?

Bananas are the staple crop of Uganda. They are grown by three-quarters of farmers, and consumed by Ugandans in greater numbers than any other country.[a] However, yields have been in decline for the last decade. The banana crop is under attack from a host of pests such as weevils and nematodes, and diseases such as black sigatoka, fusarium wilt and bacterial xanthomonas wilt (BXW). BXW is especially pernicious as external signs of the disease are often invisible in plantlets, so it is easily spread as farmers exchange planting material.

Conventional breeding faces a number of difficulties in developing resistant varieties because bananas have relatively narrow genetic diversity and are not propagated by seed. In response, the Ugandan government has invested heavily in biotechnology R&D, opening a National Agricultural Biotechnology Centre in 2003, which has received support from donors such as USAID, the Rockefeller Foundation and the Bill and Melinda Gates Foundation. In the pipeline are biofortified bananas and varieties with resistance to pests and BXW, all of which are unable to progress beyond the stage of confined field trials (CFT) owing to a lack of biosafety regulation; attempts to pass new legislation through the Ugandan parliament stalled amid considerable controversy.

Anti-GM activists have, in the words of one interviewee, ‘created heat and thrown up dust to create confusion around the bill’ with some success. Opponents of GM have played on fears of health risks, for example claiming links with cancer, obesity and infertility, and using lurid images of deformed cattle and human babies growing from GM maize plants. Campaigners have also focused on social-justice issues, portraying the proposed biosafety law as a concession to big business that will erode farmers’ rights and undermine ‘food sovereignty’, despite the fact that the contested technologies have been developed as public goods without the participation of TNCs. These tactics have undermined consumer confidence and led to concerns among farmers that their costs will increase, their ability to exchange plantlets will decline and their markets will collapse. Government voices – presumably fearful of the toxic politics of GM – have remained largely absent from the national debate, with no clear communication of the potential benefits from the technology or rationale for public investment. Without widespread support among farmers – a key political constituency in Uganda – the biosafety bill remains on ice.

While the anti-GM campaign has been highly successful in polarizing the debate and stalling the political process, it has done so at the expense of an opportunity for a balanced and substantive conversation about the risks and benefits of the technology. For example, while the potential benefits of BXW resistance are obvious – one study estimated the lack of a BXW-resistant variety could cost Ugandan farmers $295 million a year in crop losses[b] – experts interviewed during this research identified two potential risks relating to the widespread introduction of the GM variety. First, it could reduce genetic diversity among Uganda’s existing banana crop, resulting in the potential loss of valuable genetic material in the absence of a well-functioning seed bank to maintain genetic resources. Second, large-scale mono-cropping of the BXW-resistant variety could render banana production vulnerable to the emergence of a new strain of xanthomonas or a new banana pathogen to which the GM variety lacks specific resistance. These are precisely the kinds of risks that a functioning biosafety regime would evaluate. Unfortunately in Uganda, rather than engaging with valid concerns such as these, the national debate is preoccupied with largely invalid fears fomented by campaigns of misinformation and scaremongering.

Sources: Chatham House and NRI field research.

[a] Uganda National Banana Research Programme, http://www.banana.go.ug/index.php/about-us/background.
[b] Kalyebara, M. et al. (2006), ‘Economic Importance of the Banana Bacterial Wilt in Uganda’, *African Crop Science Journal*, Vol. 14, No 2.

Consumer and farmer impacts

African governments might be more willing to invest political capital in developing enabling regulatory environments if there was countervailing demand from farmers (or food consumers) for GM technology. However anti-GM campaigns mean that consumers are often suspicious or afraid of GM foods. This in itself deters farmers. Campaigns have also raised concerns about the high costs of GM technologies and exploitative practices of TNCs. For example, in Uganda, where a number of GM staple crops have been developed as public goods, anti-GM campaigning often based on misinformation and shocking imagery has undermined confidence among consumers and farmers and almost certainly delayed the passage of tabled biosafety legislation (see Box 2).

The role of the EU

Robert Paarlberg and others have argued that the prohibitive politics of biotechnology in Africa are largely rooted in Europe.[25] This was a view commonly held by those interviewed for this research. Proposed linkages between the EU and Africa include:

- NGOs campaigning against GM in Africa are often linked to European NGOs opposed to GM, through affiliation or funding relationships.
- European donors have promoted the development of highly precautionary biosafety regimes in Africa through bilateral and multilateral aid, and technical assistance programmes.
- The absence of a European consumer market for GM produce discourages adoption by export-oriented farmers in Africa.

Continuous field trials: a convenient deadlock

In combination, political and institutional factors operate to funnel biotechnology development towards the field-testing stage, but prevent it from progressing further. The result is a steady state of continuous CFTs. This suits the interests of public researchers, who are able to ‘do science’ and generate publishable research, and fits within the often short funding timelines of donors. It allows governments to manage political risks by effectively balancing the demands of pro- and anti-GM lobbies – proponents of GM have a pipeline of technologies, while opponents are appeased by the failure of any to gain approval. A 2010 survey of selected Africa countries by the Forum for Agricultural Research in Africa identified ongoing GM R&D projects for cowpea (stem borer resistance), rice (nitrogen use efficiency, salt tolerance, water use efficiency), sorghum (biofortification), sweet potato (virus resistance, weevil resistance), maize (water use efficiency), banana (bacterial xanthomonas wilt resistance, black sigatoka resistance, fusarium wilt resistance, weevil and nematode resistance, biofortification, delayed ripening, early maturity), cassava (mosaic virus resistance, brown streak

[25] Paarlberg, *Starved for Science*. See also European Academies Sciences Advisory Council (2013), ‘Planting the Future’ for a summary of the literature on this point.

resistance).[26] In total, these potentially represented 18 crop traits at the CFT or pre-CFT stages of development. Assuming an average cost of $101 million to bring a crop trait to the trial stage, this portfolio could represent a potential investment commitment of approximately $1.8 billion.[27]

Three years later, none had passed the field trial stage. Table 1 summarizes a 2013 review of GM crop development in Africa, excluding previously commercialized Bt and glyphosate resistance traits. The CFT bottleneck is clearly evident. Also noteworthy is the predominance of public research institutions over private corporations, participation of the latter typically being in the form of IP donation. Donor funding is commonly provided by a select number of philanthropic foundations – in particular Bill & Melinda Gates and Rockefeller – and USAID. The only European donor is the UK Department for International Development (DFID).

Table 1: GM crops in development in sub-Saharan Africa

Country	Crop/Trait	Institutions	Status
Burkina Faso	Cowpea/pod borer resistance	AATF, CSIRO, IITA, Kirkhouse, Monsanto, NARS, NGICA, PBS, Rockefeller Foundation, USAID	Confined field trials
	Rice/water efficient, nitrogen use efficient, salt tolerant	AATF, Arcadia Biosciences, CIAT, Japan Tobacco, NARS, PIPRA, Univ. California, DFID, USAID	Laboratory regeneration
	Sorghum/biofortified with iron and zinc	AATF, Africa Harvest, CSIR, ICRISAT, NARS, Pioneer, Danforth Center, Univ. California, Univ. Pretoria, Gates Foundation, Howard G Buffett Foundation	Confined field trials
Ghana	Rice/water efficient, nitrogen use efficient, salt tolerant	AATF, Arcadia Biosciences, CIAT, Japan Tobacco, NARS, PIPRA, Univ. California, DFID, USAID	Laboratory regeneration
	Cowpea/pod borer resistance	AATF, CSIRO, IITA, Kirkhouse, Monsanto, NARS, NGICA, PBS, Rockefeller Foundation, USAID	Confined field trials
Kenya	Cassava/mosaic and brown streak resistance	Danforth Center, ETH Zurich, KARI, Gates Foundation, Howard G. Buffett Foundation, Monsanto Fund, USAID	Confined field trials
	Cassava/biofortified with iron, protein and vitamin A	Danforth Center, ETH Zurich, NARS, Gates Foundation	Confined field trials
	Maize/stem borer resistance	CIMMYT, KARI	Confined field trials
	Maize drought tolerance	AATF, CIMMYT, Monsanto, NARS, Gates Foundation, Howard G. Buffett Foundation, USAID	Confined field trials

[26] Not including crop traits developed for non-African markets, such as Bt cotton and glyphosate resistant maize. See Forum for Agricultural Research in Africa (2010), 'Biotechnology Management in Africa', http://www.fara-africa.org/media/uploads/File/sabima/biotechdatabase__online.doc. Note that this survey only included data for Burkina Faso, Ghana, Nigeria, South Africa and Tanzania.

[27] Based on McDougall (2011) 'The cost and time involved', where total costs of $100.9 million on average are estimated for the stages of GM development from discovery to introgression breeding and wide-area testing (i.e. not including regulatory science, registration and regulatory affairs). Note that this is an indicative estimate only, and may represent an upper limit as it assumes cost estimates from a sample of international companies are applicable in the African context, where labour costs, facility costs and regulatory costs may be lower. It also includes costs for advanced research that may not be relevant in cases where early stage IP is donated. Funding data on African GM projects against which to compare this are scarce. One partial benchmark is the Water Efficient Maize for Africa (WEMA) project – a 10-year initiative funded with an initial five-year grant of $47 million by the Bill & Melinda Gates and Howard G. Buffett foundations, with additional funding from USAID and donations in kind from Monsanto, indicating that total costs over the life of the project are likely to be of comparable size to the McDougall estimates.

	Sorghum/biofortified with iron and zinc	AATF, Africa Harvest, CSIR, ICRISAT, NARS, Pioneer, Danforth Center, Univ. California, Univ. Pretoria, Gates Foundation, Howard G Buffett Foundation	Confined field trials
	Sweet potato/weevil resistance	Auburn Univ., BecA, CIP, Danforth Center, Kenyatta Univ., NaCRRI-Uganda, NARL-Uganda, Univ. Ghent, Univ. Puerto Rico, Gates Foundation, Howard G. Buffett Foundation	Greenhouse containment
Mozambique	Maize/drought tolerance	AATF, CIMMYT, Monsanto, NARS, Gates Foundation, Howard G. Buffett Foundation	Stalled: awaiting regulatory framework
Nigeria	Cassava/biofortified with iron, protein and vitamin A	Danforth Center, ETH Zurich, NARS, Gates Foundation	Confined field trials
	Cowpea/pod borer resistance	AATF, CSIRO, IITA, Kirkhouse, Monsanto, NARS, NGICA, PBS, Rockefeller Foundation, USAID	Confined field trials
	Rice/water efficient, nitrogen use efficient, salt tolerant	AATF, Arcadia Biosciences, CIAT, Japan Tobacco, NARS, PIPRA, Univ. California, DFID, USAID	Laboratory regeneration
	Sorghum/biofortified with iron and zinc	AATF, Africa Harvest, CSIR, ICRISAT, NARS, Pioneer, Danforth Center, Univ. California, Univ. Pretoria, Gates Foundation, Howard G Buffett Foundation	Confined field trials
South Africa	Maize streak virus resistance	Pannar Seed, Univ. Cape Town	Greenhouse containment
	Maize/drought tolerance	AATF, CIMMYT, Monsanto, NARS, Gates Foundation, Howard G. Buffett Foundation	Greenhouse containment
	Sorghum/biofortified with iron and zinc	AATF, Africa Harvest, CSIR, ICRISAT, NARS, Pioneer, Danforth Center, Univ. California, Univ. Pretoria, Gates Foundation, Howard G Buffett Foundation	Greenhouse containment
Tanzania	Maize/drought tolerance	AATF, CIMMYT, Monsanto, NARS, Gates Foundation, Howard G. Buffett Foundation	Stalled: awaiting regulatory framework
Uganda	Banana/bacterial wilt resistance	AATF, Academia Sinica, IITA, NARO-Uganda, Gatsby Foundation, USAID	Confined field trials
	Banana/parasitic nematode and weevil resistance	NARO-Uganda, Univ. California, Univ. Leeds, Univ. Pretoria, Bioversity International, Government of Uganda, Rockefeller Foundation, USAID	Confined field trials
	Banana/biofortified with iron and vitamin A	NARO-Uganda, Queensland Univ. of Technology, Gates Foundation	Confined field trials
	Cassava/mosaic and brown streak resistance	Danforth Center, ETH Zurich, NaCRRI, Gates Foundation, Howard G. Buffett Foundation, Monsanto Fund, USAID	Confined field trials
	Sweet potato/weevil resistance	Auburn Univ., BecA, CIP, Danforth Center, Kenyatta Univ., NaCRRI-Uganda, NARL-Uganda, Univ. Ghent, Univ. Puerto Rico, Gates Foundation, Howard G. Buffett Foundation	Greenhouse containment
	Maize/drought tolerance	AATF, CIMMYT, Monsanto, NARS, Gates Foundation, Howard G. Buffett Foundation, USAID	Confined field trials

Sources: Namuddu, A. and Grumet, R. (2013), 'Genetically Modified Crops Under Research in Africa', African Biosafety Network of Expertise, http://www.nepadbiosafety.net/subjects/biotechnology/gm-crops-under-research-in-africa, and Edmeades, G. (2013), 'Progress in Achieving and Delivering Drought Tolerant Maize', http://www.isaaa.org/resources/publications/briefs/44/specialfeature/Progress%20in%20Achieving%20and%20Delivering%20Drought%20Tolerance%20in%20Maize.pdf.

Breaking the deadlock

The current situation of continuous field trials without release may be politically and scientifically convenient, but it represents poor value for money for the donors and foundations funding research, and it is of no value to African farmers or consumers. The above discussion implies a number of leverage points at which the deadlock might be broken.

Reforming regulation

An appropriate, functioning biosafety regime is often identified as crucial for the adoption of GM technologies because public and private investment requires a stable regulatory environment. Yet African governments face significant shortfalls in institutional and scientific capacity, while national regimes, where they exist, are disparate and fragmented. A common approach to biosafety could increase regulatory coherence across African countries, so reducing regulatory costs for technology providers. This could also allow governments to reap economies of scale, for example by pooling limited scientific resources for the purpose of risk assessments, or through collectively applied deregulation such that the successful testing and release of a GM variety in one country qualifies it for release in other participating countries.

But the challenges of developing a regional approach should not be underestimated. The track record of African governments on delivering effective regional policy frameworks is patchy at best, and the lack of political capital associated with GM technology indicates that a shift in the politics of GM is needed before a regional regulatory framework might become a feasible prospect.

Nor does the absence of a regulatory framework necessarily prevent farmers from adopting GM varieties. The first GM crops to be grown in India were from illegal Bt cotton seeds, with regulatory approval following soon after. Bt varieties have now been adopted by over 90 per cent of Indian cotton farmers.[28] It is quite conceivable that, should a GM seed emerge that mobilizes significant demand among African farmers, porous borders and the common practice of exchanging seed might see it spread without regulatory approval or in the absence of regulation entirely.

Unlocking farmer demand

The above points to the importance of farmer demand, a clear articulation of which is likely to remove political obstacles and bring forward enabling regulation. For example, the development of biosafety legislation in South Africa was in large part a response to demands from farmers to be able to grow GM maize.

Farmer demand in turn requires a product that demonstrably meets farmer needs at an affordable price. Understanding farmer needs is therefore crucial to the research process, and farmer demand is more likely if, as noted above, farmers can be engaged in the research, development and demonstration (RD&D)

[28] James, C. (2012), 'Global Status of Commercialized Biotech/GM Crops: 2012', International Service for the Acquisition of Agri-Biotech Applications.

process. This implies a bottom-up, participatory approach over the course of RD&D through which farmers become stakeholders in a nascent technology.

To take a decision to plant a GM crop, or to lobby for the release of a GM variety, farmers need access to reliable information about the technology's risks and opportunities. Where farmers can make this assessment at first hand, for example by examining the experience of early-adopting peers (as happened with the adoption of Bt cotton in India, for example) or by engaging in CFTs and demonstration projects, so much the better. But most African farmers are likely to rely on second-hand information, generated or provided via proponents or opponents of GM technology. This presents them with a major challenge owing to the highly polarized nature of the debate: they are likely to be presented with contradictory and irreconcilable accounts of the risks and benefits, and considerable amounts of misinformation. Bt cotton is a case in point. Opponents of GM have claimed that it has trapped farmers in India in a cycle of debt and is to blame for thousands of farmer suicides there, but this is not supported by evidence.[29] On the other hand, some of the benefits of Bt cotton appear to have been overstated in simplified accounts of increasing farm yields and profits (see Box 3). Bt cotton is not a cause of farmer suicides, but nor is it a magic bullet.

[29] See Gruère G., Mehta-Bhatt, P. and Sengupta, D. (2008), 'Bt Cotton and Farmer Suicides in India: Reviewing the Evidence', International Food Policy Research Institute Discussion Paper 808; and Gruère G. and Sengupta, D. (2011), 'Bt Cotton and Farmer Suicides in India: an Evidence-based Assessment', *Journal of Development Studies*, Vol. 47.

Box 3: Measuring success – contested evidence of the benefits of Bt cotton

Bt cotton, developed initially for American cotton farmers but since commercialized for smallholder farmers including in India, China and Burkina Faso, is a GM success story. Before Bt, pesticide use for cotton was typically the highest of any crop, resulting in environmental contamination, human poisoning and the accelerated generation of pest resistance. In India and China, for example, adoption rates for Bt cotton exceeded 70 per cent of farmers within 5–8 years after release[a] and have coincided with reductions in pesticide use of 50–60 per cent.[b]

The hype surrounding Bt cotton grew rapidly, particularly with respect to India. This was probably in large part a response to prominent campaigns from Indian activists claiming that the technology was unreliable, exploitative and responsible for farmer indebtedness and suicides. Proponents of Bt cotton pointed to data showing national cotton yields 'taking off' from 2002, the year in which it was approved, from around 300 kilogrammes per hectare (kg ha^{-1}) to over 550 kg ha^{-1} by 2007. Initial studies estimated substantial yield increases for early adopters in India, commonly in the range of 30–60 per cent and in one case as high as 87 per cent.[c] Studies also estimated remarkable increases in farm profitability – often between 50 and 90 per cent, as higher seed prices were more than offset by reduced losses and lower labour and pesticide costs associated with reduced spraying.[d]

Yield increases in other countries have been more modest – typically around 10 per cent.[e] The results obtained in India probably reflected poor pest management among adopting farmers, meaning that Bt cotton had a more pronounced impact on crop losses; in Australia, where Bt cotton was introduced among farmers already practising good integrated pest management, yields did not increase (though importantly pesticide use did decline). Had Indian farmers been practising better pest management in the first place, Bt cotton's impacts would probably have been more muted.

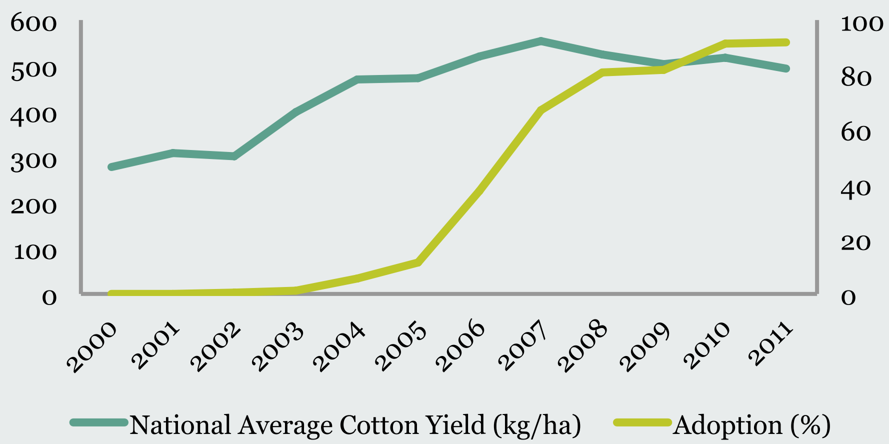
More importantly, recent analysis has questioned the extent to which early yield increases in India were attributable to Bt cotton. The rapid increase in national yields that coincided with the commercialization of Bt cotton appears to have been largely attributable to other factors. As Glenn Stone has pointed out, yield increases preceded adoption: most of the yield jump – from 302 kg ha-1 to 470 kg ha-1 – occurred between 2002 and 2004, during which time adoption climbed to only 5.6 per cent of total cotton grown. No conceivable increase in productivity among such a tiny proportion of output could explain a national yield increase of 56 per cent, though it is important to note that effective adoption rates are likely to have been somewhat higher owing to the early, unrecorded use of illegal Bt seed. Bt cotton almost certainly contributed to the huge rise, but it must be mainly attributable to a combination of other factors such as new pesticides, new non-GM hybrids, new micro-irrigation schemes and new planting areas. Since 2004, Bt adoption has continued to climb – to over 90 per cent of production today – yet yields appear to have peaked in 2007 and been in decline since.[f]

The validity of the yield increases ascribed to Bt cotton in early farmer studies has also been called into question as problems of selection bias and cultivation bias have emerged. In the case of selection bias, results are overstated because early adopters of Bt cotton tended to be better-educated, richer, higher-input farmers than the non-adopters with whom they were compared. In the case of cultivation bias, results are overstated because farmers lavish more care and attention on the new, expensive seed variety than on the cheaper non-GM variety with which the comparison is made. More recent studies attempting to compensate for these biases indicate India saw more modest yield increases from Bt cotton in the region of 20 per cent.[f] This is still an impressive increase, but a fraction of the improvements claimed in earlier analyses.

In Africa, the introduction of Bt cotton has been slower, with only farmers in South Africa and Burkina Faso planting significant acreage (Sudan has also recently adopted the crop). African farmers typically grow cotton with relatively fewer insecticide sprays than farmers in China, for example. As the economic gain from Bt cotton adoption derives primarily from the reduction in spraying costs, the benefits of adopting Bt may be less evident in Africa than in India or China.[g] Still, similar claims have been made regarding the introduction of Bt cotton in Burkina Faso and South Africa, with yield increases of 20 per cent reported.[h] However, as with India, it is possible that these higher yields, recorded in on-station and early farmer trials, may not be maintained as adoption spreads to the mass of cotton farmers, who lack the resources or knowledge that often characterizes early technology adopters. Subsequent growing seasons in South Africa have failed to demonstrate reductions in pesticide use or yield increases reported in the early literature.[i]

While the introduction of Bt cotton illustrates that farmers can rapidly adopt GM crops in developing countries, policy-makers and regulators need to exercise considerable caution and objectivity if the true causal relationships associated with the introduction of new biotechnologies are to be understood. It also indicates that no single innovation, or magic bullet, is likely to sustain significant productivity increases on its own – rather, the careful introduction of a basket of complementary innovations is needed.

Figure 1: Indian cotton yields and adoption of Bt cotton



Sources: Yield data are from the Cotton Corporation of India and adoption rates are from International Service for the Acquisition of Agri-Biotech Applications. Adapted from a similar chart in Stone (2012), 'Constructing Facts'.

[a] James, C. (2008), 'Global Status of Commercialised Biotech/GM crops: 2008', International Service for the Acquisition of Agri-Biotech Applications Brief No. 39.

[b] Huang, J.K. et al. (2003), 'Biotechnology as an Alternative to Chemical Pesticides: a Case Study of Bt Cotton in China', *Agricultural Economics*, Vol. 29; Edwards, M. and Poppy, G. (2009), 'Environmental Impacts of Genetically Modified Crops', in Ferry, N. and Gatehouse, A. (eds), *Environmental Impact of Genetically Modified Crops* (Wallingford: CABI Publishing).

[c] Qaim and Zilberman estimated yield increases of 87 per cent. A series of subsequent studies by Qaim and colleagues summarized in Stone (2012) estimated yield increases in the region of 30 to 40 per cent, while Bennett et al. estimated 45 to 63 per cent. See Qaim, M. and Zilberman, D. (2003), 'Yield Effects of Genetically Modified Crops in Developing Countries', *Science*, Vol. 299, No. 5608; Stone, G. (2012), 'Constructing Facts: Bt Cotton Narratives in India', *Economic and Political Weekly*, Vol. 47, No. 38; Bennett, R. et al. (2004), 'Economic Impact of Genetically Modified Cotton in

India', *AgBioForum*, Vol. 7, No. 3.
[d] See, for example, Bennet et al. (2004) and James (2008), 'Global Status of Commercialised Biotech/GMcrops: 2008'.
e Brookes and Barfoot find negligible yield increases from Bt cotton in Australia, 9–11 per cent in the United States, 8–10 per cent in China, 30 per cent in Argentina, 9–14 per cent in Mexico, 24 per cent in South Africa, and 6 per cent in Brazil. See Brookes, G. and Barfoot, P. (2013), 'GM Crops: Global Socio-economic and Environmental Impacts 1996–2011', PG Economics.
f Stone (2012), 'Constructing Facts'.
g Hillocks, R. (2009), 'GM Cotton for Africa?', Outlook on Agriculture, Vol. 38.
h For example, Vitale, J. et al. (2011), 'Commercial Application of GMO Crops in Africa: Burkina Faso's Decade of Experience with Bt Cotton', Journal of AgroBiotechnology Management and Economics, Vol. 13.
i Personal communication with Rory Hillocks; and Hofs, J. et al. (2006), 'Impact of Bt Cotton Adoption on Pesticide Use by Smallholders: A 2-year Survey in Makhatini Flats (South Africa)', Crop Protection, Vol. 25.

Translating research into impact

On the supply side, the institutions that shape R&D and pull technologies through the pipeline and into use could be more closely aligned with farmer needs and the context-specific constraints – such as climatic conditions, socioeconomic factors, infrastructural deficits and so on – within which they operate. As well as being disconnected from farmers, the different stages of technology development and delivery may be disconnected from each other, resulting in a process that is piecemeal and fragmented. For example, advanced scientific research may be undertaken with minimal farmer engagement, but also without a clear plan for how this may subsequently be handed on to applied scientists, adapted and eventually rolled out to farmers, or of the sources of funding for these crucial later stages.

The incentives under which different actors operate can be better aligned to delivering farmer outcomes. Innovative financing instruments that link payments to results – such as livelihood impacts among target farmers – could be one means to do so. This will be hardest to do for early-stage, advanced research, which is not only temporally (and possibly geographically) the farthest stage from farmer adoption, but also where the chance of successful farmer outcomes is smallest. Nevertheless, it may still be possible to identify appropriate early-stage laboratory results by working backwards from desired farmer outcomes and an understanding of context-specific constraints. Alternatively, incentives can be tweaked through other means, for example by requiring funding applications for advanced research to provide evidence of farmer demand and impact potential, or to include plans for how farmer needs will be assessed at the outset. Ideally, applicants would be able to show that farmers had been included in the design of a project.

As well as working to create smart, outcome-oriented incentives, donors and governments should also develop funding strategies that allow them to support technology development and delivery along the entire pipeline. Ideally, this would include longer funding horizons that enable grants to span multiple activities. National governments may have more scope than traditional donors to provide longer-term funding. At an absolute minimum, however, donors should plan for success and be prepared to fund follow-on activities or assist grantees to access follow-on funding. A more laissez-faire approach would establish challenge prizes for the adoption of technologies that demonstrably meet particular farmer needs, and allow scientists and development practitioners to design projects in response.

Ultimately, the successful development and delivery of an appropriate technology is a long-term effort involving different actors with different knowledge and capacities. Research institutions are well placed to manage discrete elements of research, but not to provide strategic direction to such complex, long-term and multi-stakeholder projects. There could be a role for more active engagement from donors and governments to help ensure this.

Crucially, in any such project, all actors must share a common goal. This implies a comprehensive 'theory of change' that articulates how the technology and accompanying interventions will lead to impact, and specifies what needs to be done, when and by whom, in order to realize this. Recognizing that a successful research outcome is not the same as a successful development outcome, a theory of change should consider, among other things analyses of:

- end-users, not only in terms of their needs with respect to the technology itself, but also in terms of the constraints within which they are operating, appropriate modes of engagement during the research process, capacity-building, and attitudes towards GM;
- accompanying interventions to support technology adoption (e.g. relating to access to finance or markets);
- relevant policy and institutional frameworks, and necessary reforms to create an enabling environment for technology adoption; and
- the wider socio-political context in relation to GM technology.

Such analyses will evolve over the lifetime of a project, so a theory of change should be continually modified as analyses change in response to contextual factors. The preceding discussion indicates that some of the principal barriers to the adoption of GM technology in Africa are institutional and political, therefore particular emphasis should be placed on robust strategies to influence relevant policy processes and engage in discussions about the technology with national stakeholders.

A systems approach: picking winners?

Individually, specific interventions on the demand or supply side are unlikely to overcome stasis. A system-wide approach, which targets multiple constraints in a coordinated fashion, is likely to be more successful. This represents a significant undertaking, going beyond technology development into policy change and regulatory reform. More fundamentally, because the potential for success ultimately depends on the political context – notably the attitudes of consumers and farmers, and the perceptions of politicians – it implies the need to shift the terms of highly polarized national debates about GM. It is questionable whether donors and their partners have the capacity to do this; it is also debatable to what extent they could justify doing so: after all, it is for African countries to decide for themselves whether they wish to accept GM technology.

In the short term, donors and partner organizations wishing to develop pro-poor biotechnologies could maximize the chances of success by refocusing efforts in a smaller number of 'best bet' countries with the most promising national conditions. In line with the principle of national-led development, donors could begin with governments expressing clear demand for biotechnology support and demonstrating political commitment through, for example, ambitious national funding programmes. Further selection criteria might include assessments of farmer and consumer attitudes to GM, the regulatory regime and appetite for reform if needed, the strength of opposition to GM and the quality of public debate about GM. Focusing efforts in a smaller number of 'best bet' countries would also allow resources to be focused on more ambitious system-wide projects with multiple supply-side and demand-side interventions, and a central role for national government. A number of donors are rightly already focusing on countries where they believe they have the greatest chances of success.

Opportunities for further research

Based on the preceding discussion, the following areas are worthy of consideration for further research.

Strategic programme governance

A common theme among interviewees for this research was the challenge of designing management arrangements for complex programmes with multiple different actors from the public and private sectors of different countries. This is compounded by the fact that activities occur along a 10–15-year timeline, ranging from knowledge generation to delivery and extension. How should a holistic programme in its entirety be conceived, steered and managed, and what does this mean in terms of specific governance arrangements? For example, issues to be explored include:

- Alignment of objectives and shared outcomes among different actors;
- Modes of engagement and coordination among different actors;
- Incentives for different actors;
- Funding arrangements that are sufficiently flexible and long-term;
- Overall programme management and strategic leadership; and
- Engagement of key stakeholders such as farmers, consumers, officials and politicians.

In particular, there may be important opportunities to learn from approaches within the private sector, and to scale up existing best practice among leading donors and research institutes.

Assessing enabling environments for biotechnology in Africa

The efficacy of biotechnology investment can be increased by focusing efforts on a smaller number of 'best bet' countries in which the political, regulatory, social and economic conditions offer the greatest chance of success. Objective assessment of countries' 'enabling environments' for biotechnology development and adoption could help donors decide where to engage, and also help create the conditions for a ‘race to the top’ among governments wishing to attract investment in agricultural biotechnology. One way to do this would be through the development of a country index that evaluates factors such as regulation, seed stewardship, public research capacity, political commitment, public and media attitudes and farmer demand.

Funding costs of GM in Africa

Progress in developing and commercializing GM traits in Africa has been disappointing. The potential benefits of success remain attractive, however. The extent to which these potential benefits justify donor funding levels is hard to assess owing to the lack of easily accessible funding data. The estimated total investment commitment of $1.8 billion included earlier is derived from a crude calculation. Research to gather financial data, map and cost current GM projects would allow this to be refined significantly. This could be used in conjunction with a country index such as that proposed above to assess the extent to which funding is flowing to enabling or disabling contexts.

Conclusion

The development of African agriculture offers important opportunities to reduce poverty and improve food security. There are significant challenges, however, not least the mounting threat of climate change. Improving farmers' access to modern crop varieties is central to the development and climate change adaptation efforts. In many cases, GM offers some advantages over conventional approaches, including faster breeding times and the potential to introduce traits from outside the crop genome. For these reasons, GM technology is supported by an influential constituency of donors, scientists and foundations. However, despite considerable investment, this support has yet to translate into anything more than successful field trials: so far no GM trait developed for African farmers has been put to use.

There are multiple barriers to the development and adoption of GM technologies in Africa, but some of the most important – such as regulatory constraints and weak farmer demand – must be understood in relation to the wider socio-political context. This context is typified by misinformation, polarized public discourse and dysfunctional and opportunistic politics. In these circumstances, top-down, technocratic projects that lack a politically astute theory of change are unlikely to succeed. This has two important implications.

First, technology development needs to be located within a wider project of transformation that engages key actors – most notably politicians, policy-makers and farmers – as stakeholders from the outset, and includes strategies to address multiple demand-side and supply-side barriers. Second, successful adoption is more likely in countries with less disabling political conditions, characterized by lower levels of consumer distrust and opposition, genuine farmer demand and demonstrable commitment from government. Focusing efforts and resources on a small number of 'best bet' countries will also allow donors and technology providers to support more ambitious, transformational projects led by national governments.

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Acknowledgments

This paper benefited greatly from the comments of Susan Seal, Liz Wilson, Joanna Chataway, Julie Howard and John McMurdy and from discussion of research findings at the Chatham House conference *Food Futures* held on the 9th and 10th of December 2013. Any errors or omissions remain the sole responsibility of the authors. Grateful thanks are also extended to the participants at a roundtable held at Chatham House on 13 June 2013 and to those who participated in research interviews. Both of these research processes were instrumental in shaping and testing the analysis presented in this paper.

Funding for the preparation of the paper, the workshop and field research was generously provided by the Charities Aid Foundation.

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