Can GMOs Deliver for Africa?

Kimberly Elliott and Janeen Madan

Abstract

The debate over genetically modified organisms (GMOs) has been raging for 20 years, and there is still more heat than light around the topic. While some developing countries have embraced the technology, much of Africa has followed the European Union's precautionary approach. So far, the implications of those decisions have not been huge for smallholder agriculture and basic food security because multinational corporations developed the current generation of GMOs with large-scale, industrial agriculture in mind. GM crops in the pipeline, such as vitamin A enhanced "golden rice," drought tolerant maize, or disease resistant bananas, could be more valuable for smallholder producers and poor consumers—if they ever make it to market.

While not a panacea, GMOs could be part of a new green revolution in Africa if governments address the policy and institutional weaknesses that prevented Africa from participating in the first one, and if GM technology continues to develop. Governments should avoid foreclosing the opportunity that GMO technology could create to address climate change effects, tropical crop diseases and pests, and micronutrient deficiencies. To help prepare for a new green revolution in Africa, and leave the door open for GMOs to be part of it, we offer recommendations which include increasing public support for agricultural R&D, developing cost-effective regulatory approaches for GMOs, promoting information exchange about experiences with GMOs, and pursuing South-South cooperation on trade policies.

Genetic modification is only one technology among many with the potential to improve agricultural productivity in Africa, and investments in the one should not be at the expense of the others. But it would be unfortunate if an overly cautious approach foreclosed the opportunity to use GMOs to significantly improve productivity or reduce malnutrition.

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Introduction

The debate over genetically modified organisms (GMOs) has been raging for twenty years and there is still more heat than light around the topic. While some developing countries have embraced the technology, much of Africa followed the European Union's precautionary approach. Up to now, the implications of those decisions for smallholder agriculture and basic food security have not been huge because multinational corporations developed the current generation of GMOs with large-scale, industrial agriculture in mind. The major GM crops—herbicide tolerant or insect resistant varieties of soybeans and maize—are used mainly for livestock feed and biofuels, and grown primarily in a handful of countries in North and South America that are major commodity exporters. Only cotton genetically-modified to resist certain insects has been widely adopted in developing countries, mainly in India and China.

GM crops in the pipeline, such as vitamin A enhanced "golden rice," drought tolerant maize, or disease resistant bananas, could be more valuable for smallholders producers and poor consumers—if they ever make it to market. Even then, many of the agro-ecological and other obstacles that kept Sub-Saharan Africa from participating in the first green revolution would have to be overcome, including weak infrastructure and poorly functioning markets (for both inputs and outputs). And, despite the increased attention to agriculture since the 2007-2008 price spikes, many countries are still underinvesting in research, development, and dissemination of technologies that could improve productivity.

Thus, fixing the policy and institutional weaknesses that reduce incentives to invest in agriculture should be the top priority in Africa. But many governments there are also taking a highly precautionary approach to GMOs, in part because the European Union is a major export market and strictly regulates the importation of GM products. The costs of following the EU approach could grow substantially if it blocks the opportunity to use GMOs in the future to address serious challenges prevalent across the continent, including the effects of climate change, tropical crop diseases and pests, and micronutrient deficiencies.

This paper surveys the current status of GM crops and where the technology is heading.[1] It then analyzes how the currently dominant crops and traits have not delivered as hoped for developing country farmers and consumers, while technologies under development could be more beneficial. It then turns to an examination of the constraints to exploiting agricultural biotechnology for development in Africa. An update of Paarlberg's (2006) analysis of the commercial risks to African adoption of GM crops confirms that it is small. Institutional and policy weaknesses are serious, however. We conclude with recommendations that would

[1] This research is in the spirit of an earlier project funded by the UK Department for International Development that concluded that it is not appropriate to make broad, general statements such as whether "GM is a good or bad thing for the developing world," because it depends on the political, economic, and policy context (IDS 2003).

help African governments keep their options open and allow them to take advantage of a breakthrough technology that could help raise farmer productivity or tackle undernutrition.

Where Do Things Stand, and What's in the GMO Pipeline?

Flavr Savr, a tomato variety genetically modified to slow down ripening and preserve flavor, became the world's first commercially available GMO when the United States approved it for cultivation in 1994. Since then the GMO pipeline has expanded to include different traits introduced into a range of crops grown in 28 developed and developing countries. But just four crops—soybeans, maize, cotton, and rapeseed—and two traits—herbicide tolerance and insect resistance—dominate the GMO landscape today (James 2014). While new varieties of those crops and traits remain prominent in the pipeline of products under development, a number of new crops and traits that might be more valuable for developing countries appear at various stages of development.

Scientists use a wide variety of techniques to produce improved crop varieties, all of which in some sense involve genetic modification.[2] To date, the most controversial technique has been transgenesis, which involves inserting a gene from one species into another with the goal of introducing a desirable trait. Agricultural researchers use transgenesis and other genetic engineering techniques because they can be faster than conventional breeding. Transgenesis is also more targeted than other techniques, such as mutagenesis, which scrambles an organism's own genes in the search for helpful mutations. Newer genome editing techniques, such as CRISPR, could be faster and cheaper yet (Travis 2015). And, perhaps, these gene editing techniques will trigger less controversy if they can be used to produce allergy-free peanuts or save the Cavendish banana from disease, and because they do not involve the introduction of foreign DNA (Reardon 2016). There is some indication that US and EU authorities may not regulate GE foods using the CRISPR technique as GMOs for that reason.[3] Most of the commercially available GM crops today are the result of transgenesis, which is what we mean when we refer to GMOs or GM crops.

There is a broad scientific consensus that well-regulated GMOs are not riskier than conventionally bred crops and are safe to eat (Ronald 2011, p. 12; Key et al. 2008). It is impossible to prove a negative, however, and many people remain concerned, particularly about unintended environmental consequences.[4] The European Union maintains tight

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[2] Nathaneal Johnson dissects how "It's Practically Impossible to Define 'GMOs'" on The Grist blog (December 21, 2015), last accessed March 6, 2016 at http://bit.ly/1Ika6Fp.

[3] See Adele Peters, "CRISPR Is Going To Revolutionize Our Food System—And Start A New War Over GMOs," *Fast Company*, March 15, 2016, accessed March 18, 2016 at http://bit.ly/1pJ66Gc.

[4] It is difficult to know how deep the concern really is. Food writer Tamar Haspel noted in a *Washington Post* column that, when asked if they wanted GMOs labeled, polls frequently show that 80 to 90 percent or more say yes. Yet, when asked an open question about what information they would like to see on food labels, only 7 percent said GMOs. The Haspel column is here http://wapo.st/1nvV8D4 and the 2013 Rutgers report showing small numbers volunteering GMOs as something they want to see on labels is here http://bit.ly/1Im62AM, both accessed March 29, 2016.

controls on GMOs, despite two reviews of EU-funded research that covered "more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups" that concluded that "biotechnology, and in particular GMOs, are not *per se* more risky than e.g. conventional plant breeding technologies" (EU Commission 2010, p. 16). There are growing concerns that the way farmers *use* GMOs could pose environmental risks, including from increased pest resistance as discussed below. Though scientists argue, again, that the risks are not greater than with conventional crops in a large, commercial agriculture setting (van Montagu 2010, p. 21-22). There also needs to be special scrutiny of, and perhaps restrictions on, GM varieties that will be planted in areas where wild relatives are present if contamination is possible. Finally, more post-release analysis of GMO use and consumption could help to identify any previously undetected effects before they become a major health or environmental problem.

The first generation of crops and traits

The current generation of GM crops is the product of private sector investments in technologies for industrial agriculture, with American farmers as first adopters. Herbicide tolerant (HT) crops have been engineered to tolerate the active ingredients in less toxic, broad spectrum herbicides, such as Monsanto's RoundUp (the brand name for glyphosate).[5] Insect resistant (IR) varieties are engineered using genes from a soil bacterium, Bacillus thuringiensis (Bt), which produces a protein that is toxic to certain insects.[6] These GM crops are not inherently higher yielding. But they do increase yield in areas where farmers face pest pressures and lack access to alternative means of weed or insect control.

US authorities approved Monsanto's RoundUp Ready soybean seeds for commercial cultivation in 1996. Today, RoundUp Ready and other HT varieties are available for more than ten commodities, and are the most widely adopted GM crops.[7] In commercial agriculture systems, HT varieties allow farmers to save on labor and other input costs. Glyphosate is relatively less expensive than alternative, narrow-spectrum herbicides, and it allows farmers to manage their land without tilling, which also prevents soil erosion and the release of greenhouse gas emissions. At least initially, farmers did not have to spray as often and the overall use of herbicides dropped. That is now changing because heavy reliance on glyphosate is leading to superweeds that are resistant to its effects.[8]

The most widely adopted IR crops are Bt maize, mainly for livestock feed and other industrial purposes, and Bt cotton. The IR trait allows farmers to manage pests with lower

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[5] More on herbicide tolerance and RoundUp Ready crops is here http://bit.ly/1SkqBzK, accessed February 26, 2016.

[6] Bt crops can be bred using a variety of Bt genes to target different types of insects. More information is summarized at http://bit.ly/1SkrwjI.

[7] Data are from ISAAA GM Approval Database at http://bit.ly/1dUOYp0, accessed February 26, 2016.

[8] William Neuman and Andrew Pollack, "Farmers Cope With Roundup-Resistant Weeds," *New York Times*, May 2010, accessed February 26, 2016 at http://nyti.ms/1SuqB2Q.

chemical use, which again saves on labor and other input costs. US regulations require farmers to plant non-GMO "refuges" around fields planted with Bt crops, so that susceptible insects will survive and breed with any Bt-resistant insects that develop. Despite those precautions, Bt-resistant pests are emerging in some areas.[9]

Increasingly, seed companies are selling varieties with "stacked traits," where genetic engineering allows for two or more desirable traits to be combined.[10] Seeds with both HT and IR traits are the most common stacked varieties, especially in maize, cotton, and soybeans. These stacked traits are most prevalent in the United States, where they were grown on over 60 percent of the total GM crop area in 2014 (James 2014, p. 200). They have also been adopted by farmers in Brazil, Canada, China, and India.

HT varieties account for just under 60 percent of the total area planted with GM crops, far ahead of the stacked trait and insect resistant varieties that make up the balance (figure 1a). All other traits account for just 0.1 percent of the total area planted to GM crops. HT varieties have consistently been the most popular among farmers since GM crops were commercialized in the mid-1990s. Stacked trait varieties overtook crops with just the IR trait in 2006 (James 2014, p. 199). Soybeans and maize are the dominant GM crops, accounting for 80 percent of the total. Cotton and canola (also known as rapeseed) account for most of the rest (figure 1b). Most of the GM soybeans grown globally now have an HT trait (James 2014, p. 194).

The global distribution of GM crops

The global land area planted to GM crops increased from 1.7 million hectares in 1996 to 182 million hectares in 28 countries in 2014 (James 2014, p. 7). Of these, 10 are high-income and 18 are classified as low and middle income countries (figure 2a). More than 75 percent of the total area of GM crops was cultivated in just three countries, however—the United States, Brazil, and Argentina (figure 2b). So, while the International Service for the Acquisition of Agri-biotech Applications (ISAAA) reports that developing countries recently surpassed developed countries in terms of the land area planted to GM crops, Brazil, India, and China accounted for 82 percent of it.

The ISAAA also reports that nearly 90 percent of GM crop adopters by the mid-2000s were resource poor farmers in developing countries. This is explained, however, by the large number of farmers in India and China who cultivate Bt cotton on small plots of land (Paarlberg 2006, p. 83). And of the developing countries approving commercial cultivation of a GMO, only Burkina Faso is classified as low income.[11] Across all of Sub-Saharan Africa,

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[9] Philip Brasher and Stephen Davies, "Rootworm resistance to Bt maize prompts new EPA requirements," *AgriPulse*, February 18, 2016, accessed February 26, 2016 at http://bit.ly/21RIOtA.

[10] More on gene stacking is here http://bit.ly/1VRSC7r, accessed February 26, 2016.

[11] Under the World Bank's most recent classification for 2016, Bangladesh, which has approved Bt eggplant cultivation, is now categorized as a lower middle income country.

only two other countries—South Africa, and Sudan—allow the cultivation of GM crops. All three African countries cultivate Bt cotton, while South Africa also grows GM varieties of maize and soybeans. Together these three countries account for less than 2 percent of the total global area planted to GM crops. The story is much different in Latin America, where nine countries in addition to Brazil and Argentina are growing GM crops.

Where governments allow GM crops, adoption rates are often quite high. In the United States, more than 90 percent of the maize, cotton, and soybean acreage is planted with biotech varieties, while in Brazil it is more than 90 percent of soybeans and winter maize, and almost two-thirds of cotton (James 2014, p.16, 33). Globally, 82 percent of soybean acres and 68 percent of cotton acres are planted with GM varieties, with adoption rates over 90 percent for cotton in India and China (James 2014, pp. 54, 77, 203).

In sum, the first generation of GM technology has been dominated by two traits and four main crops. Moreover, two of these crops (maize and soybeans) are mostly grown in North and South America for livestock feed and biofuels. While regulators have approved a handful of food crops for cultivation, few farmers have adopted them because of fears that a negative consumer response (including by food companies) would leave them without a market. In addition, the HT trait is better suited to industrial agricultural systems, where farmers have ready access to affordable chemical inputs. Thus far, only Bt cotton, which replaces the need for chemical inputs, has been widely adopted by smallholder producers in developing countries.

The pipeline of new crops and traits

Although HT and IR traits in maize and soybeans remain prominent, there are a number of other crops and traits in the research pipeline with greater potential to address pressing agricultural challenges in developing countries. Figure 3 shows the distribution of GMOs by trait and stage of development as of 2014 (Parisi et al. 2016).[12] Close to 80 percent of all GM varieties at the commercial and pre-commercial stages are for HT and IR varieties, including where the two traits are stacked in a single plant. But that falls to around 40 percent at the regulatory and advanced R&D stages.

Other traits under development are more relevant for farmers in developing countries and have the potential to raise yields and improve food security in the face of climate change. Traits at various stages of development include drought resistance (abiotic stress tolerance), disease resistance, increased yield, and bio-fortified varieties to address undernutrition (modified product quality). And while these traits collectively only account for a fifth of total GM varieties at the commercial and pre-commercial stages, they comprise a growing share at the regulatory and advanced R&D stages. Over 30 percent of GMOs at the regulatory stage

[12] The source calls these "events," which the authors define as a unique DNA recombination in a plant cell that is then used to generate a transgenic plant. Each plant line derived from a transgenic event is considered a GMO.

were for varieties with improved product quality, such as micronutrient fortification. And as figure 3 depicts, GM varieties at the advanced R&D stage are more evenly distributed across the different traits.

In addition to new traits, a broader range of crops are also under development. Figure 4 shows the total number of potential products by crop and development stage. Through 2014, soybeans, cotton, maize, and canola dominated at the commercial and pre-commercial stages.[13] Notably, there are an additional 12 potential soybean varieties at the advanced R&D stage. But there is a handful of different crops in the pipeline, including several potato and rice varieties at the regulatory and advanced R&D stages. In addition, as of 2014, field trials were ongoing in 7 African countries on a range of staple crops, including maize, wheat, sorghum, bananas, cassava, and sweet potato.[14] Figure 4 also shows that a number of varieties of fruits and vegetables (namely tomato, papaya, eggplant, and squash) are still in the early regulatory and R&D stages. Overall however, there are fewer efforts to develop GM fruits and vegetables, compared to the dominant staple and cash crops.

To reiterate, HT and IR varieties of maize, soybeans, cotton, and canola in a handful of countries dominate the GMO landscape. New crops with the potential to address some of the key agricultural challenges in Sub-Saharan Africa are under development. And an increasing number of low and middle income countries are approving commercial cultivation of GM crops. As the research pipeline expands to include new crops and new traits developed through partnerships between private and public sector actors, dissemination and adoption will depend on developing countries having robust policies in place to approve and safely regulate GMOs.

The policy environment for GMOs

There are broadly speaking two approaches to regulating GMOs. The European Union follows the precautionary principle and tightly regulates GMOs, including imports. The United States accepts GMOs as being generally as safe as their conventional counterparts, and that leads to a lighter regulatory touch. Policies across Sub-Saharan Africa have been highly influenced by the European Union's precautionary approach, while most of Latin America has followed the more open US approach (Paarlberg 2013). Other emerging countries are taking generally cautious approaches, but with significant variation (see box 1).

Under the European Union's precautionary approach, regulators can withhold approval for new GM varieties based on the possibility of harm if there is no clear evidence of safety. The

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[13] The study authors define commercial stage as "currently being cultivated and commercialized in at least one country; pre-commercial stage is defined as "authorized for cultivation in at least one country worldwide but not yet marketed (commercialization depends on the developer's decision)".

[14] The 7 countries are Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria, and Uganda. See James 2014, p. 11.

European Union does not start from the premise that GM products are essentially the same as non-GM products, and it regulates the cultivation and consumption of GM products separately. By contrast, the United States regulates GM crops and derivative products using the same agencies and laws governing conventional crops and products (ibid., pp. 207-208). US regulators focus on the attributes of the final product and whether genetic modification could be the source of any new toxic substances or allergens in consumption of the product, or environmental risks from cultivating it.

In addition to the European Union's policies, there are two other major influences driving the risk-averse regulatory approach of many Sub-Saharan African countries (Chambers et al. 2014, pp. 42-45). The first is the Cartagena Protocol on Biodiversity, which endorses the precautionary approach and has been adopted by 170 countries.[15] In relation to trade, it states that countries exporting GMOs for food and feed use must notify importing countries that products "may contain living GMOs." The second is the African Union Model Law on Safety in Biotechnology (formerly the African Model Law on Safety in Biotechnology), which is designed to shape biosafety legislation across the continent. It underscores the precautionary principle and calls for regional harmonization of policies on imports, exports, and marketing (Chambers et al. 2014, p. 45).

Influenced by these policies in the early 2000s, several Sub-Saharan African countries imposed bans on GMOs, including cultivation and imports for food, feed, and industrial use. At one extreme, countries like Zambia imposed bans even for food aid. Others, such as Malawi and Tanzania, made exceptions for imports of GM grains that had been milled.[16] As of early 2016, with the exception of Angola and Kenya, these bans have been lifted. In some countries like Ethiopia and Ghana where cotton, soybean meal, and soybean oil are imported from the large GM producing countries (United States, Argentina, and Brazil), shipments that may contain GMOs remain unregulated.[17]

GMOs Not Yet Living Up to the Promise for Developing Countries

GMO proponents focus on the need to substantially increase the quantity and quality of food available to the poor (for example, Paarlberg 2006; Federoff 2015; Chambers et al. 2014). Doing that sustainably, in the words of one plant scientist, means that "increased food production must largely take place on the same land area while using less water" (Ronald 2011, p. 11). And this will have to happen in the face of more frequent extreme

[15] More information on the protocol is at http://bit.ly/1qf2Z9e and the full text of the agreement is here http://bit.ly/1MQvrmK, accessed February 26, 2016.

[16] For a more detailed summary of bans imposed by African countries, see Chambers et al. 2014, p. 60.

[17] USDA Agricultural Biotechnology Annual Reports for 2015 for Ethiopia and Ghana are available at http://1.usa.gov/1Sksfl2 and http://1.usa.gov/1UAbsRf.

weather events due to climate change. So yields have to increase, and crops need to be more resilient in the face of environmental stresses.

Technology is clearly an important part of the answer, but how important are GMOs? The current generation of GM crops—dominated by two traits and just four crops—is not making a major contribution to global food security or poverty alleviation among smallholder producers, especially in Africa. Given the experience in India and China, we could probably expect more African producers to plant Bt cotton if their governments permitted it. But the limited range of the current selection of crops and traits is an important factor limiting the reach of commercially available GMOs.[18] There are also growing questions about the environmental effects of the currently available varieties, especially the increased use of herbicides with HT crops.

In assessing the impact of this set of GM technologies, it is important to note that any yield gains are explained by reduced crop losses due to pests, not because the seeds themselves are higher-yielding than conventional seeds. That is the reason that we would expect to see relatively higher yields from using HT or IR varieties in developing countries and among poorer farmers who have less access to alternative pest controls and pest pressures are high. Most impact studies in developing countries focus on Bt cotton, because that is the most common GMO in commercial cultivation. Those studies find yield increases of 24 percent to 37 percent in China and India, respectively, versus a yield gain of just 10 percent in the United States (Barrows et al. 2014, p. 105).

A metasurvey of studies on the effects of GMOs finds empirical evidence of the benefits to producers, especially from the use of IR varieties (Klumper and Qaim 2014):

- higher yields, particularly in developing countries;
- lower pesticide use, but higher costs overall because of higher seed costs; and
- higher farmer profits because increased yields offset higher costs.

The herbicide-tolerant crops are a more mixed story. According to the same metasurvey (ibid.):

- the average yield gains are less than for IR crops and more variable;
- herbicide use is higher, but glyphosate is less toxic than alternative herbicides; and
- the limited data available show large, but statistically insignificant, effects on farmer profits.

Other studies suggest that the principal gain from HT crops is the reduction in labor required. In developed countries, this is due to the reduced need to till the soil and, in some

[18] GMO maize is mostly yellow maize, used for livestock feed, not the white maize varieties that people typically eat (James 2014, p. 198).

cases, fewer applications of herbicides. In developing countries with less access to chemical controls, farmers spend fewer hours weeding (Thompson 2015, pp. 306-307). But these crops require farmers to buy both improved seeds and herbicide, which may be out of reach for many poorer farmers with limited access to inputs. And for those farmers who can afford to use HT varieties, the fact that the technology reduces the need for labor in very poor rural areas is not necessarily a benefit.

Among the other potential benefits of GM crops are improvements in human health and the environmental impact of agriculture (Barrows et al. 2014, pp. 107-113). When these crops improve yields, they are land-saving, which is a benefit from the perspective of climate change mitigation. The lower pesticide use with IR crops is associated with fewer farmer chemical poisonings and more biodiversity in affected fields. Impact studies have found reductions in pesticide use with Bt cotton of up to two-thirds in China and around one-third in the United States and South Africa (ibid., p. 109). And HT seeds allow farmers to use no till management practices, which contributes to better soil quality, less runoff, and fewer carbon emissions.

These environmental and health benefits are at risk, however, because of growing pest resistance. Pest resistance is also a problem with conventional crops, but it seems to be accelerating with the use of HT and IR GMOs (Barrows et al. 2014, p. 108). In particular, the near exclusive reliance by farmers on glyphosate in conjunction with HT crop varieties is contributing to the emergence of superweeds that are resistant to the chemical.[19] Far from reducing the need for chemicals, adoption of HT crops led to a *15-fold* increase in the use of glyphosate in the United States, and, after an initial decline, a rebound in overall herbicide use on soybeans (Benbrook 2016). Glyphosate is less toxic than other herbicides, but a World Health Organization agency labeled it as probably carcinogenic in 2015. And no one really knows what the impact of such a large increase in its use might be on human health.[20] Moreover, as the widespread use of glyphosate is leading to resistance in weeds, farmers are turning back to more toxic chemicals (Benbrook 2012). The US Department of Agriculture (USDA) also reported that soybean farmers in the United States slightly reduced their use of no till practices from 2006 to 2012.[21] And seed companies are responding by stacking traits, so that newer varieties can tolerate the more toxic chemicals in combination with glyphosate.

Another review of the existing literature on GMOs suggests caution in interpreting the results of the studies showing producer gains in developing countries (Smale et al. 2009, p.

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[19] Natasha Gilbert, "A Hard Look at GM Crops," *Nature,* vol. 497, May 2, 2013.

[20] A summary of the WHO findings is at http://bit.ly/1m8MEAh, accessed March 10, 2016. After the European Food Safety Authority conducted a review and concluded that the herbicide was "unlikely to pose a carcinogenic hazard to humans," more than 90 scientists published an article in the *Journal of Epidemiology and Community Health* arguing that the EFSA study was flawed, available at http://bit.ly/1pqlAiq, accessed March 10, 2016. Benbrook (2016, pp.11-12) discusses glyphosate's other potential health effects.

[21] See the summary of the most recent USDA Agricultural Resource Management Survey for the soybean industry, last accessed March 3, 2016 at http://1.usa.gov/1p2rnKf.

80). These authors emphasize that the methodologies used have significant limitations and that the results showing gains *on average* mask significant variation:

The magnitude of the economic advantages varies substantially according to the nature of the cropping season and the geographical location of the study. This would be the case whether or not the seed introduced were transgenic, but the variation is particularly pronounced for IR crops.

The producer gains in developing countries are particularly vulnerable, however (Smale et al. 2009, p. 82). The integrated pest management practices that are needed to keep insect or pest resistant GMOs effective are resource and knowledge intensive, but resistance is growing even among American farmers with access to all kinds of tools and information sources.[22] One of the practices required in the United States, for example, is to plant refuges (areas planted with non Bt crops) around fields with Bt crops to hinder the development of resistance. Poor farmers in developing countries with tiny plots may not have the knowledge or resources to do this. Weak extension services and regulatory institutions in developing countries make this a particular concern (Chambers et al. 2014, p. xviii). Ronald (2013, p. 5) notes that bollworm resistance to Bt in India seems to have been accelerated by the widespread adoption of GM cotton in the absence of such refuges.

Can the Next Generation of GMOs Deliver for Developing Countries?

Many of the crops and traits that are in the pipeline could be far more valuable for smallholder producers and food insecure consumers in developing countries. Moreover, they are less likely to raise concerns about overuse of chemicals, or the dominance of a few major seed companies wielding intellectual property rights to lock farmers into their products. And a growing number of these crops are getting closer to commercial cultivation in developing countries. For example two years ago, Bangladeshi farmers began planting Bt eggplant, which could improve yields and reduce pesticide use. Monsanto donated the Bt technology, the locally adapted variety was developed by public research institutions (with financial support from USAID), and it is available royalty-free to farmers who will also be able to save and reuse seeds.[23]

Other researchers are working to develop new traits such as increased tolerance to drought, flooding (submergence), and salinity that would be particularly useful for developing country producers. And the crops under development are not just maize and oilseeds for large, industrial operators, but also rice and sugarcane. Others are working to increase the nutritional value or disease resistance of staples such as cassava, cowpeas, and sweet potatoes. New GM varieties could also bring a range of environmental benefits if scientists

[22] Jacob Bunge, "EPA to Require Seed Companies to Tighten Defense Against Pests in Biotech Corn," *Wall Street Journal,* February 28, 2016, accessed March 9, 2016 at http://on.wsj.com/1Vqx13m.

[23] More information is at http://bit.ly/1RIvlP3, last accessed March 9, 2016.

succeed in their efforts. One goal is to modify plants to use nitrogen more efficiently, which would improve water quality by reducing runoff and lower GHG emissions. It could also be a boon for smallholder producers that have difficulty affording fertilizer.

But there are substantial technical, political, and economic challenges that still have to be overcome. Many of the varieties under development to address abiotic stresses involve more complex processes than inserting a single new gene to convey insect resistance, for example. Drought tolerance involves a range of genes that have to be manipulated to achieve the desired result (Gilbert 2014, p. 292; Ricroch and Henard-Damave 2015, p. 8). Early results for Monsanto's DroughtGard maize variety so far show relatively modest improvements in yields under water stress and, as of 2014, less than one percent of maize acres were planted with the new seeds in the United States.[24] A report in *Nature* found that conventional breeding techniques are producing faster results in trying to produce maize varieties adapted for Africa that are more drought-tolerant or use nitrogen more efficiently.[25] Finally, when scientists seek to improve a product's characteristics that are useful for consumers but not directly related to productivity, they have to ensure that the new variety has yields that are at least comparable to its conventional counterparts. Otherwise, farmers will not adopt it. One reason that Vitamin A enhanced golden rice has not yet been released commercially is that crop yields have been disappointing (James 2014, p. 221).

Public resistance is a still a problem for GM food products, however. If the technical problems can be overcome, new GM varieties will have to offer more obvious benefits to consumers or the environment to have any chance of countering resistance. And because developing country markets are relatively small and poor, a substantial part of the resources for research and development of these new varieties will have to come from the public sector, donors, and via public-private partnerships. Thus, while a number of GMOs under development could offer significant benefits to developing country producers and consumers, the obstacles to success are large, especially in Africa.

Risks and Opportunities for Sub-Saharan Africa

Despite progress, Sub-Saharan Africa is lagging behind the rest of the world in reducing hunger and poverty. Most people in Africa still live in rural areas and rely on agriculture for some part of their livelihoods. Moreover, a 2015 World Bank report on global hunger and poverty notes that declines in poverty in Sub-Saharan Africa have been closely correlated with increases in cereal yield (Townsend 2015, p. 7). Agricultural and food products are also a quarter of Sub-Saharan Africa's non-extractive exports. Improving agricultural productivity is critical to the continent's future.

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[24] See http://bit.ly/1O8oHAV, last accessed March 3, 2016.

[25] Natasha Gilbert, "Cross-bred crops get fit faster," *Nature,* vol. 513 (September 18, 2014): p. 292.

Genetic modification could contribute, but there are a number of constraints that Africa will have to overcome.[26] Among the constraints that have deterred African governments from investing in GM technology is a concern about export markets. Even if those concerns can be overcome, there are significant shortfalls in the research, institutional, and regulatory capacity needed to develop and exploit this technology for agriculture in Africa.

Would GMO adoption threaten African agricultural exports?

A decade ago, Robert Paarlberg analyzed African trade data to assess whether allowing the cultivation of GMOs was likely to threaten African exports to European and other "GMO-sensitive" markets. In 2002, in the midst of a severe drought, Zambia had refused to accept US food aid because it was likely to contain GM maize. Other countries in the region required that maize donations be milled so farmers could not plant it. At the time, the governments cited concerns that GM maize might contaminate local maize supplies and lead the European Union to block exports (Paarlberg 2006, p. 85).

Using highly conservative assumptions about the degree of GMO sensitivity in major African markets, Paarlberg concluded that only Egypt had a "legitimate fear" of export losses as high as 10 percent. For all other countries, he concluded that, even in his worst case scenario, the commercial risks from planting GMO crops would be "vanishingly small" (ibid., p. 89). Smale et al. also find that "many studies demonstrate that in developing economies, [concerns about] potential export losses resulting from the adoption of transgenic crops are unjustified relative to the potential gains from productivity enhancement" (2009, p. 87).

Our update of Paarlberg's analysis confirms that the risks to African exports of adopting the current GM varieties are small. The largest market for African agricultural exports, by far, is still the European Union. But of the top ten destinations for Sub-Saharan African agricultural exports in the aggregate, the European Union is the second slowest growing, ahead of only Japan (table 1). China surpassed the United States as the second largest market for African agricultural exports in 2012, while India is just slightly behind. And exports to the Chinese and Indian markets, along with several others in Southeast Asia, are growing far faster. Taken together, agricultural exports within Sub-Saharan Africa constitute the second largest market, though growth there is slower compared to the emerging markets and other countries in Asia.

While the European Union market remains the most important, Africa's agricultural exports there, and to the rest of the world, are still mostly tropical or subtropical products that are not prominent subjects of biotechnological research (Parisi et al. 2016; Chambers et al. 2014, Appendix A). Cocoa, fruit (mostly citrus, grapes, bananas, and cashews), coffee, tea, and spices, tobacco, and cotton accounted for $26 billion out of $35 billion in total average

[26] Wedding and Nesseth Tuttle 2013 analyze these constraints in detail for three east African countries: Kenya, Tanzania, and Uganda.

exports in 2012-14 (table 2). Figure 5 shows the top exports by product and destination. For the European Union and United States, cocoa dominates, followed by fruits and coffee, tea, and spices. China imports primarily cotton, sesame seeds, and tobacco. Cashews dwarf everything else in India.

Of the major African exports, only cotton has a commercially available GM variety, while work on disease-resistant bananas is in the advanced R&D stage. The EU has approved imports of GM cotton, but Africa exports very little there. For bananas, however, the EU takes $500 million of the nearly $800 million in African banana exports. Beyond cotton and bananas, ongoing research in Africa that has advanced as far as field trials involve mostly staple crops that would not be traded outside the region, including cassava, cowpea, maize, rice, sorghum, sweet potato, and wheat (Parisi et al. 2015; James 2014, p. 223). Of the top ten African exporters (table 3), only South Africa is currently producing GM crops (cotton, maize, and soybeans). Cameroon, Ghana, Kenya, Nigeria, and Uganda have field trials ongoing.

Not only are developing country markets faster growing, some are also showing more openness to GMOs than the European Union. Vietnam recently permitted imports of GM maize, while Indonesia approved drought-tolerant sugarcane for commercial cultivation in 2013 (James 2014, pp. 219-220). Chinese farmers have embraced Bt cotton and the government seems supportive of using biotechnology to promote food security. It has approved a range GM food crops, including rice, sweet peppers, and tomatoes, though it appears that only disease-resistant papaya is widely cultivated (James 2014, p. 76, 82). On the import side, China has thus far approved imports of maize, rapeseed, and soybean products, but mainly for animal feed (see box 1). In early 2016, the government-owned China National Chemical Corporation made an offer for Syngenta, a major multinational pesticide and seed company based in Switzerland that has developed a number of GM varieties.[27]

Bangladesh is showing that a very poor country can make use of the technology as well. Within months of the government approving it in late 2013, a small numbers of Bangladeshi farmers started planting Bt eggplant. The Bangladeshi Agricultural Research Institute reported in August 2015 that the first year of planting had gone well, with far less insect predation than in conventional varieties.[28] But other reports on how it is working are as split as they are in the broader debate over GMOs.[29] It will also be crucial to see whether the authorities, if adoption scales up, are able to continue effectively enforcing the requirements to keep a refuge around the Bt crops to slow the development of insect resistance.

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[27] Keith Johnson, "Why Is China Spending $43 Billion for a Farming Company?" *Foreign Policy,* February 15, 2016; John Revill and Brian Spegele, "Syngenta Agrees to $43 Billion ChemChina Takeover," *The Wall Street Journal,* February 3, 2016, all accessed March 4, 2016 at http://atfp.co/1TlCzgs and http://on.wsj.com/1P5nkpf.

[28] A blog post about the institute's press conference is available at http://bit.ly/1LammKh, accessed March 4, 2016.

[29] See for example, on the pro side, http://bit.ly/1U7DFOq, and on the anti side http://bit.ly/1LMbOky and http://bit.ly/1fJWaHd; for a more balanced report, see http://bit.ly/1M2Z6sn, all accessed March 4, 2016.

Nevertheless, this is a promising example of how the technology can be adapted for smallholders and contribute to food security.

India, by contrast, put a moratorium on Bt eggplant trials in 2010 and prohibits GM imports, except for soybean products, which it permits for food as well as livestock feed. And only Bt cotton is approved for cultivation. The government of Prime Minister Narendra Modi, however, resumed approvals for GMO field trials in 2014, including for brinjal (eggplant), chickpeas, mustard, and rice (James 2014, 64-65).

Therefore, it seems that, for now, many developing country governments are intrigued by the potential of GM crops to improve agricultural productivity and food security but are proceeding cautiously. Since few of Africa's major exports appear in the GMO development pipeline, concerns about losing market share seem to be as inflated as they were when Paarlberg (2006) examined the issue a decade ago. Still, unless and until food crops achieve more consumer acceptance in large markets such as India and China, Africa may want to continue concentrating on local staple crops that would mostly be traded regionally. Even that, however, requires significant progress in addressing GMO regulatory and trade issues across the continent.

Capacity and other constraints to developing GMOs in Africa

Even if African governments accept that the risk to their exports is low, there are other significant obstacles to developing and disseminating GM varieties that would promote improved productivity and food security in the African context. A study commissioned by the African Development Bank and conducted by the International Food Policy Research Institute (Chambers et al. 2014) concluded that, for most countries in Africa, the capacity to do this—including human resources, technical capacity, infrastructure, financial resources, and the policy or legal climate—was "seriously deficient." Given that much of the research effort is targeting minor staple crops that are important for poor African consumers and smallholder producers, the resources will mostly have to come from African governments' own budgets, or those of donors. In some cases, major international companies have been willing to donate the gene technology, but it still has to be inserted and shown to work in a locally adapted crop variety. Thus, African policymakers need to carefully weigh the potential costs and benefits of investing in GM technologies versus other approaches (ibid., p. xiv).

Public support for agricultural R&D across Africa mostly fell, or was stagnant, from the 1970s through the mid-1990s, however, and it has fallen further since then (Spielman and Zambrano 2013; Chambers et al. 2014, pp. 26-30). Average expenditures rose modestly from the late 1990s into 2008, but remained stagnant or dropped as a share of agricultural GDP, and then fell by more than a quarter in real terms from 2008 to 2011 (figure 6; Chambers et al. 2014, p. 27). South Africa, Kenya, and Nigeria support agricultural R&D at well above the African average, spending between of $250 million and $450 million annually. But these three countries account for 50 percent of total spending across the 39 countries for which data are available. Data on public investments specifically for biotechnology are not readily available but two studies found that it was a tiny fraction of total support for agricultural R&D (Falck-Zapeda et al. 2003; Falck-Zapeda et al. 2008).

Private sector R&D investments by large multinational companies in the United States and Europe were estimated to be roughly half of the global total investment in plant biotechnology in the 1990s (Spielman and Zambrano 2013, p. 188). As discussed in previous sections, however, the first generation of crops and traits were designed for large-scale, industrial agriculture and has limited relevance for developing country needs. The disincentives to private sector investments in GM crops for Africa include underdeveloped seed markets and weak property rights over improved varieties that make it difficult for private sectors innovators to recoup R&D costs (Spielman and Zambrano 2013, p. 188-89). Poor rural infrastructure, low purchasing power of smallholder farmers, and the fact that African farmers often grow a range of local staple crops, with each having a relatively small market share, are also deterrents to private investment in improved seed varieties of any type (Chambers et al. 2014, p. 30).

Public private partnerships (PPPs) are one instrument for overcoming some of these obstacles (Spielman and Zambrano 2013, p. 189-190). These partnerships bring together a range of actors, including:

- private multinational and domestic companies that donate propriety technology (Monsanto, Mahyco, an Indian seed company);
- national public research institutes that serve as the technology recipient (Kenya Agriculture Research Institute);
- public or philanthropic funders (USAID, Gates Foundation); and
- international consortiums and NGOs that serve as intermediaries, support national research institutes, and mobilize resources (CGIAR centers, ISAAA). [30]

For example, the Water Efficient Maize for Africa (WEMA) project is developing a maize variety with stacked drought tolerance and Bt traits. Monsanto donated the Bt technology to public agricultural research institutions in South Africa, Kenya, Mozambique, Tanzania, and Uganda and the US Agency for International Development, the Bill and Melinda Gates Foundation, and the Howard G. Buffet Foundation are providing financial support (James 2014, p. 231). The initiative is not limiting its efforts to GM technology, however, and is using conventional breeding and other techniques as well to see which will be faster and more effective. Chambers et al. (2014, pp. 30-32) discuss a number of other examples of PPPs that were ongoing in Africa at the time of the study.

Spielman and Zambrano (2013, p. 194) report that in one survey of 54 African research institutions, only about a fifth of the GM product development efforts they had under way involved private sector participation. A second, more in-depth study found that the main

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[30] Drawn from examples listed in Chambers et al., 2014, p. 30-32.

purpose of PPPs with multinational companies was to facilitate technology transfer and manage intellectual property issues. In PPPs, such as the WEMA project, the multinational company holding the patent will allow seeds developed by the partnership to be sold royalty-free (Wedding and Nesseth Tuttle 2013, p. 11). In discussing the results of this research, however, Spielman and Zambrano (2013, p. 196) note that:

In general, these projects did not leverage other private-sector assets, such as scientific expertise in working with agbiotech research tools or expertise in navigating regulatory processes to bring research into commercial use.

Another key obstacle is the widespread absence of sound regulatory policies to guide the development, testing, and commercialization of GM crops. Many African countries have not yet developed national biosafety laws or other regulatory mechanisms for biotech crops, and relatively few have progressed even as far as confined trials. In recent years, a few countries have adopted national biosafety policies and passed legislation to regulate the cultivation and import of GMOs, including in Nigeria (2015), Mozambique (2014), and Uganda (2012). But a recent report commissioned by the African Development Bank concluded that the regulatory environment on the continent was characterized by "confused and disaggregated" approaches and "inefficient and technically weak policies lacking in procedural rigor" (Chambers et al. 2014, 37).

To address these challenges, the UN Environment Program, the International Food Policy Research Institute, and the Bill and Melinda Gates Foundation are funding initiatives to strengthen capacity and assist countries in developing national biosafety policies and frameworks. In parallel, regional economic communities across the continent have been making efforts to harmonize regulatory processes, especially as they relate to trade (Chambers et al. 2014, p. 39, 45). Many African countries, however, still look to the European Union as a model in this area and are following a precautionary approach that could stifle innovation in this area (Paarlberg 2013, pp. 214-16).

Thus, biotechnology offers opportunities for African countries in their efforts to strengthen their agricultural sectors and improve food security. And the risks in terms of lost export markets are overall small. If governments choose to move forward, they will, first, have to make a political decision to do so, and then they will need to invest in building the capacity to develop and safely manage the dissemination of GM crops. In generating the political will, governments face something of a chicken and egg dilemma, as described by Spielman and Zambrano (2013, p. 201):

Success may depend on the emergence of a real breakthrough—the successful navigation through regulatory processes and deployment through commercial channels of a crop that can make a real difference to small-scale, resource-poor farmers. Such a breakthrough could demonstrate the technology's potential to contribute to the region's development, as well as the importance of the processes needed to make this contribution. However, if the impediments … persist, the pace of research, development, and dissemination will be insufficient to generate such a breakthrough, thus slowing the diffusion of new technological opportunities and the potential gains to social and economic welfare in Africa.

Conclusions and Recommendations

The widespread adoption of GM soybeans, maize, and cotton seeds attests to the fact that farmers find value in this technology. High adoption rates for insect resistant cotton varieties in China, India, and parts of Africa demonstrates that the gains are not necessarily limited to large, commercial operations in developed countries. Moreover, Bt cotton reduces the need for pesticides and is associated with fewer farmer poisonings. But the benefits for developing countries outside of Latin America have been almost entirely in that one sector (cotton) and the potential for improved staple varieties to promote food security is so far unrealized. The environmental and health benefits of herbicide tolerant crops are also being lost because widespread use is leading to Roundup-resistant superweeds and to farmers turning back to more toxic chemicals.

Future benefits of the technology for food security and smallholder productivity could be greater, however, if it accelerates the development of crops that are more nutritious, resistant to tropical diseases and pests, and resilient in the face of climate change. If the technology succeeds, governments on the continent will still have to overcome the agro-ecological and other obstacles that kept Sub-Saharan Africa from participating in the first green revolution, including weak infrastructure and poorly functioning markets for both inputs and outputs. And, despite the increased attention to agriculture since the 2007-2008 price spikes, many countries are still underinvesting in research, development, and dissemination of all forms of technology to improve productivity.

Thus, fixing the policy and institutional weaknesses that reduce incentives to invest in agriculture should be the top priority. Then, realizing the opportunities from agricultural biotechnologies will require more buy-in from governments and the private sector in Africa, as well as support from donors. We make five recommendations that donors and most African countries could take to keep their options open while preparing to take advantage should a technological breakthrough occur:

1. Increase public support for agricultural R&D overall, without precluding GMOs.
2. Develop cost-effective regulatory approaches for GMOs, regionally where possible.
3. Promote information exchange about experiences with GMOs.
4. Pursue South-South cooperation, especially with countries currently cultivating GMOs, such as Argentina and Brazil, and those, such as India and China, that could be future markets.
5. Donors, including the European Union, should provide technology-neutral support for R&D to improve staple crops, as well as capacity building for segregation of GM varieties in the case of cash crops for export.

First, across most of Sub-Saharan Africa, governments need to increase public support for R&D, not just for biotechnology but across the board to address productivity shortfalls in African agriculture. Second, to reduce uncertainty for potential investors and to make sure that any resulting breakthroughs can be safely disseminated and put to use by farmers, African governments need to fix the policy environment. Rather than following the European approach of creating parallel regulatory structures, African governments could reduce the costs of GMO regulation by using existing laws and regulatory institutions, and strengthening their capacity as needed to monitor and evaluate GMOs. It would also be less costly and allow the exploitation of economies of scale if national governments would collaborate on developing regional approaches to the use, trade, and regulation of GMOs. Third, investments could be better targeted and regulatory efforts more cost-effective with increased information sharing on the risks and opportunities revealed by the experiences of other developing countries with GMOs. Spielman and Zambrano (2013, p.199) recommend using the online, open access Biosafety Clearing House for this.

Fourth, since agriculture accounts for a quarter of Africa's non-extractive exports, governments need to address the potential trade risks from adopting GMOs. Analysis of African trade data and GM varieties in the pipeline suggests the risks are not currently large. But finding ways to address them would give governments more confidence in pressing ahead. Since European attitudes towards GMOs are unlikely to change, and other markets are growing more rapidly, African governments should establish dialogues and cooperation mechanisms with other developing countries on trade in GMOs. Brazil and Argentina could share information on how they deal with domestic safety issues, as well as how they handle regulatory issues in Europe and other export markets. Dialogue among Africa, China, and India in developing regulatory and trade policies with respect to GMOs could also help to prevent unnecessary trade disruptions in those markets.

Fifth, while maintaining their own precautionary policies if they choose, EU policymakers should support African governments in making their own choices about the role of GMOs in their countries. This could include providing technology-neutral support for R&D on staple crops that are unlikely to be traded outside the continent. It should also include financial and technical support in countries that want to pursue GM cash crops and would need help building the capacity to segregate GM varieties from conventional varieties for export markets.

Genetic modification is only one technology among many with the potential to improve agricultural productivity in Africa, and investments in the one should not be at the expense of the others. But it would be unfortunate if an overly cautious approach foreclosed the opportunity to use GMOs to significantly improve productivity or reduce malnutrition. Moreover many of the investments required—in rural infrastructure, better functioning seed and input markets, and access to credit—would contribute to agricultural productivity across the board. When it comes to using agriculture to reduce poverty and improve food security, Africa needs an all hands on deck approach.

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Boxes, Figures, and Tables

Box 1: Status of policies on GMOs for 5 largest importers of agricultural products from Sub-Saharan Africa

Country	Overall policy	Approvals for import	Domestic cultivation
EU	In line with its precautionary approach, EU legislation requires mandatory safety approval of GMOs for cultivation, import and marketing; as of March 2015 individual members can ban cultivation in their countries. Zero tolerance policy for non-approved GMOs. Import shipments containing traces of non-approved products can be turned away at the border.	Approval register contains 58 GM varieties of 6 crops: maize, cotton, soybean, oilseed rape, and sugar beet. GM imports (GM soybean meal is the largest import) mainly used for feed; very little used for food.	Maize
China	Mandatory safety approval process for domestic cultivation and imports. Imports of GMO products must have a pre-approved permit from the Ministry of Agriculture; imports are quarantined at port to verify ingredients.	GM varieties approved for cotton, rapeseed, soybean, and maize. Maize and soybean only approved for processing into oil, meal and as animal feed. China is the world's largest importer of soybeans (majority are GM varieties from Brazil, US, Argentina).	Cotton, papaya, poplar, sweet pepper, and tomato
US	Policies are favorable and use the "substantial equivalence" principle to assess safety, i.e.: products derived from GMOs are regulated under same laws as conventional products. USDA, FDA, and EPA are the three primary regulatory agencies.	GM foods are not a restricted category in the food supply; products derived from GMOs are categorized as "generally recognized as safe," and do not require specific pre-market approval.	Maize, soybean, canola, cotton, squash, papaya, potato, sugar beet, and alfalfa
India	Approval process for research and commercial cultivation governed by a range of government authorities; regulatory environment fraught with political challenges. Ban on GM imports (with one exception). No GM food crops cultivated. Slow shift to more favorable attitude since 2014 under Prime Minister Modi; government has recently approved a limited number of field trials.	Only soybean oil derived from GM soybean has been approved for import for food and feed use.	Cotton

Russia	Mandatory safety approval process and registration system of GMOs and GM food products for import, processing, and sale. Russia does not grow GM crops—no regulation in place to approve commercial cultivation.	GM varieties approved for import include maize, potato, rice, sugar beet, and soybean for food; maize and soybean for feed.	None
Sub-Saharan Africa	Majority countries follow the precautionary approach. Regulatory policies are characterized as uncoordinated, technically weak, and lacking procedural rigor. Series of initiatives funded by UNEP, IFPRI, and Gates Foundation to strengthen capacity to develop biosafety policies, and ongoing efforts through regional economic communities (COMESA, ECOWAS) to harmonize regulatory processes relating to trade.	In early 2000s, several countries imposed import bans; some countries also banned food aid (Zambia) while others excluded milled grains from bans (Malawi, Tanzania). Most countries have lifted bans, except Kenya and Angola. But in many countries imports of soybean oil, cotton and processed foods that may contain GMOs remain unregulated (Ghana and Ethiopia). Several countries are currently formulating or have recently passed legislation (Nigeria 2015, Mozambique 2014, Uganda 2012) to regulate GMOs including imports.	Commercial cultivation in— Burkina Faso: Cotton Sudan: Cotton South Africa: Cotton, maize, and soybean

Sources: Compiled from ISAAA GM Approval Database, 2014; Agricultural Biotechnology Annual Reports for 2014 and 2015, USDA Global Agricultural Information Network; "Restrictions on Genetically Modified Organisms," Library of Congress, March 2014; and Chambers et al. 2014.

Figure 1a: Share of Global Area under GM Cultivation by Type of Trait, 2014

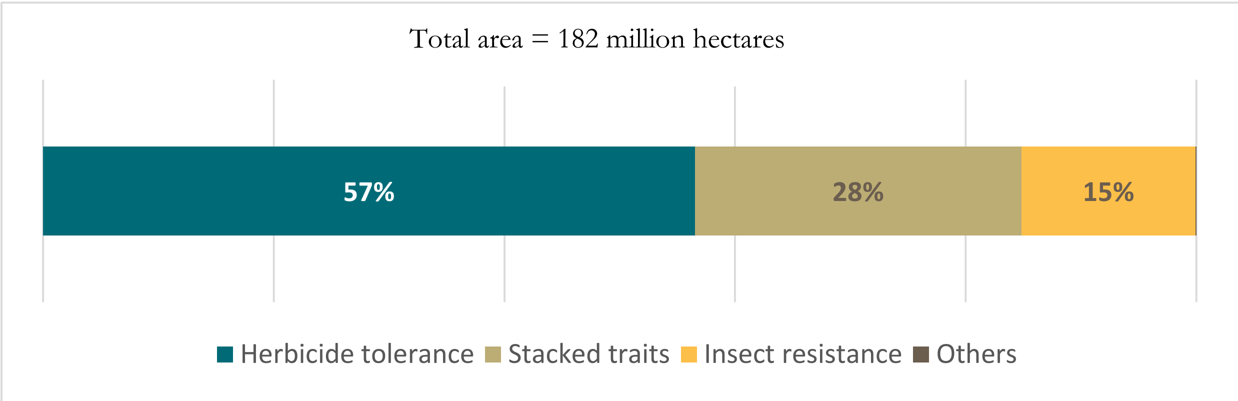
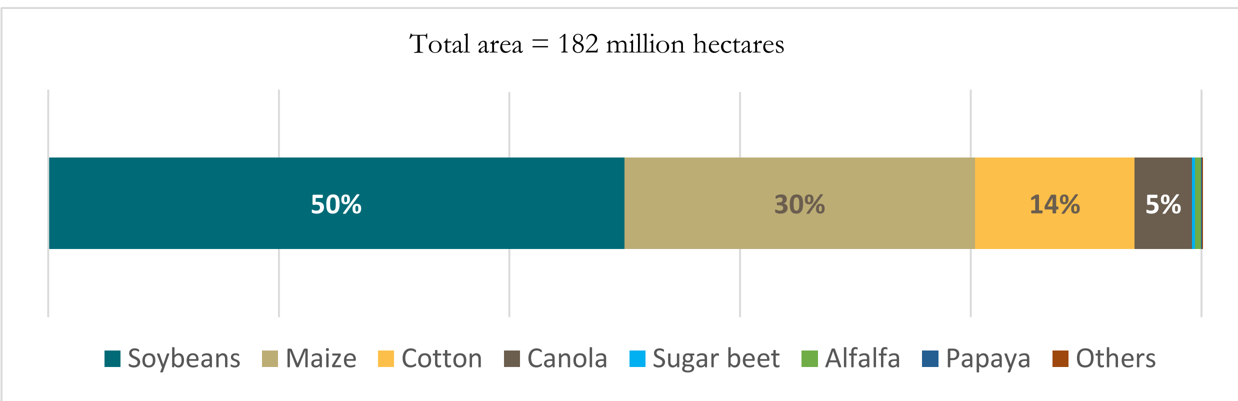
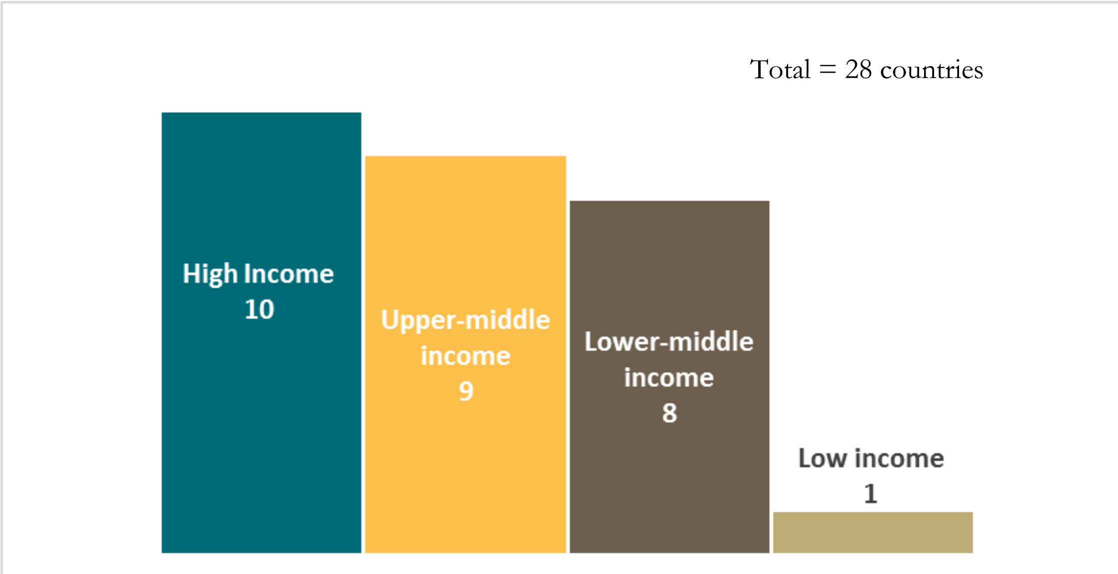


Figure 1b: Share of Global Area under GM Cultivation by Type of Crop, 2014



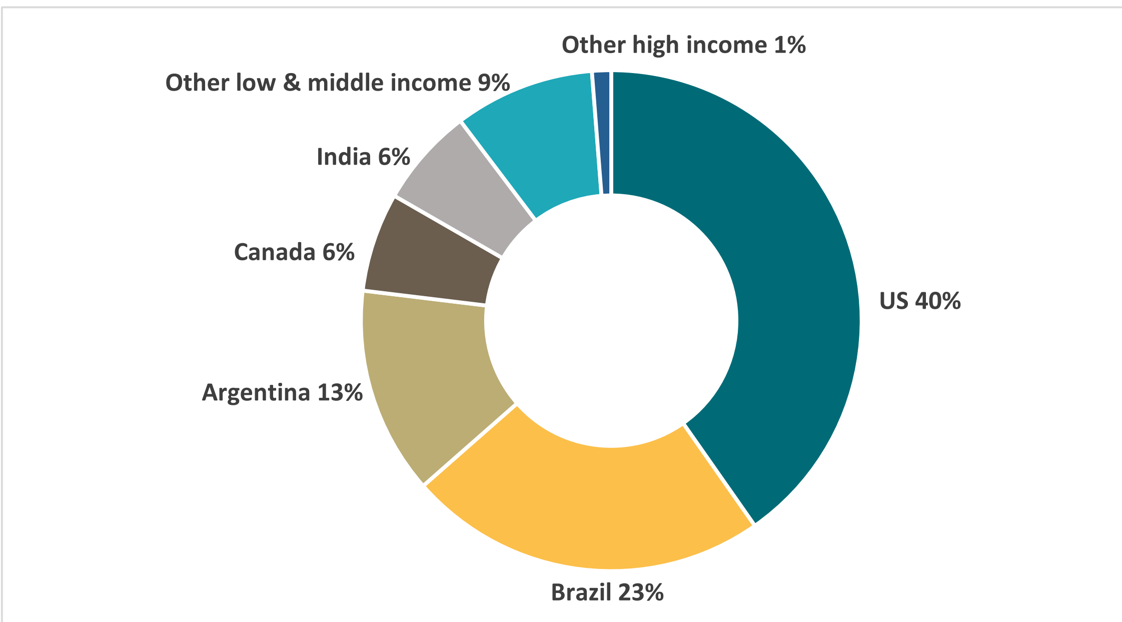
Source: Clive James, 2014.

Figure 2a: Countries Cultivating GM Crops by Income Group, 2014



Source: Clive James, 2014 and World Bank country and lending group classifications, 2016.

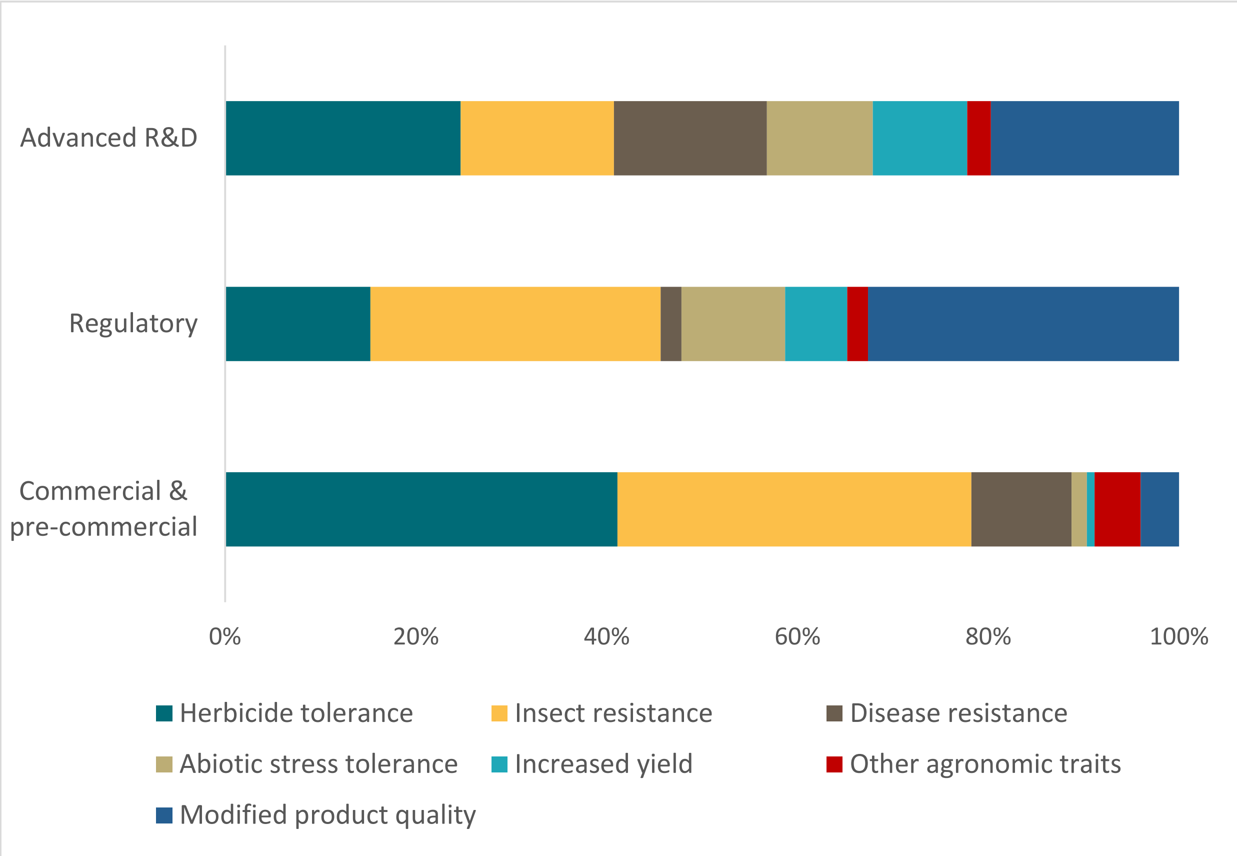
Figure 2b: Share of Global Area under GM Cultivation by Country, 2014



Notes: The United States, Argentina and Canada are classified as high income, Brazil is classified as upper-middle income and India is classified as lower-middle income; Other high income countries include: Australia, Spain, Uruguay; Other low and middle income countries include: China, Paraguay, Pakistan, South Africa, Bolivia, Philippines, Burkina Faso, Myanmar, Mexico, Colombia, and Sudan

Source: Clive James, 2014 and World Bank country and lending group classifications, 2016.

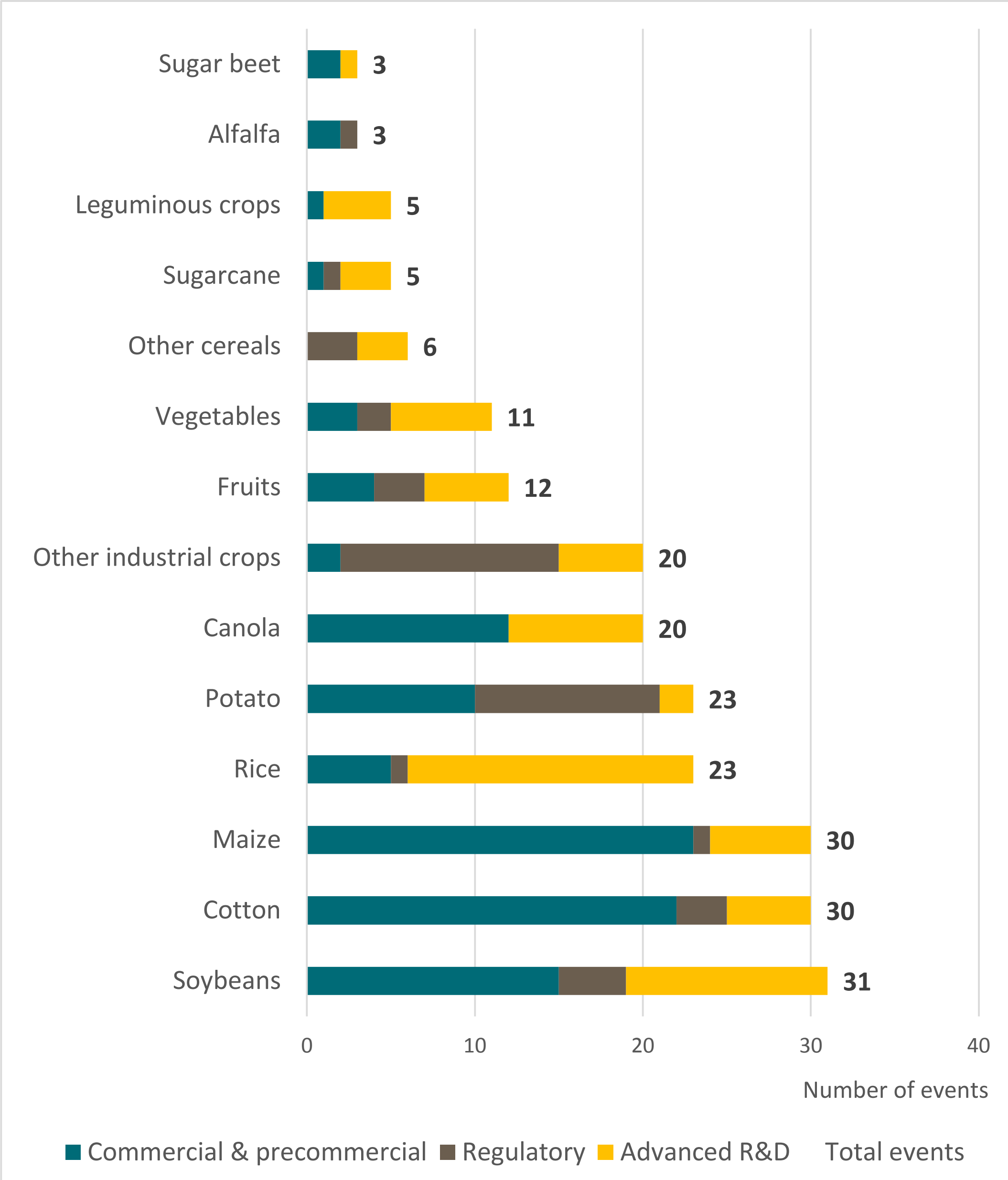
Figure 3: GM Varieties by Trait and Development Stage, 2014



Note: GM varieties refers to "events," defined as a unique DNA recombination in a plant cell that is then used to generate a transgenic plant. Each plant line derived from a transgenic event is considered a GMO. Data represent events up to 2014. Commercial cultivation corresponds to commercialized GM events (those currently marketed in at least one country); pre-commercial stage refers to GM events authorized in at least one country, but not yet commercialized (commercialization depends only on the decision by the developer); regulatory stage corresponds to GM events already in the regulatory process to be marketed in at least one country; and advanced R&D stage corresponds to GM events not yet in the regulatory process but at late stages of development (large-scale, multi-location field trials, generation of data for the authorization dossier).

Source: Parisi, Tillie and Rodriguez-Cerezo 2016.

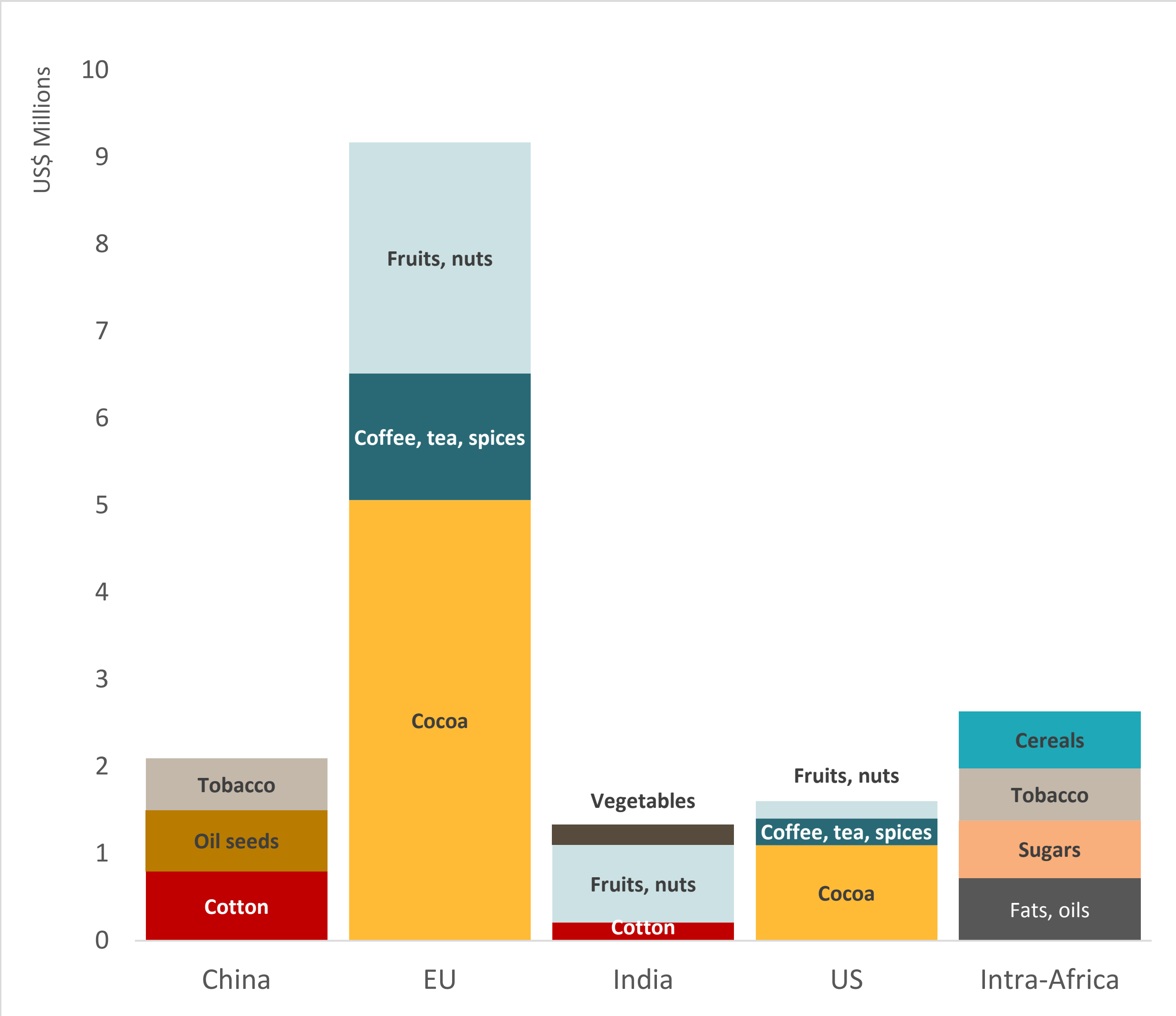
Figure 4: GM Varieties by Crop and Development Stage, 2014



Note: GM varieties refers to "events," defined as a unique DNA recombination in a plant cell that is then used to generate a transgenic plant. Each plant line derived from a transgenic event is considered a GMO. Data are for GM events up to 2014. Commercial cultivation corresponds to commercialized GM events (those currently marketed in at least one country); pre-commercial stage refers to GM events authorized in at least one country, but not yet commercialized (commercialization depends only on the decision by the developer); regulatory stage corresponds to GM events already in the regulatory process to be marketed in at least one country; and advanced R&D stage corresponds to GM events not yet in the regulatory process but at late stages of development (large-scale, multi-location field trials, generation of data for the authorization dossier).

Source: Parisi, Tillie and Rodriguez-Cerezo 2016.

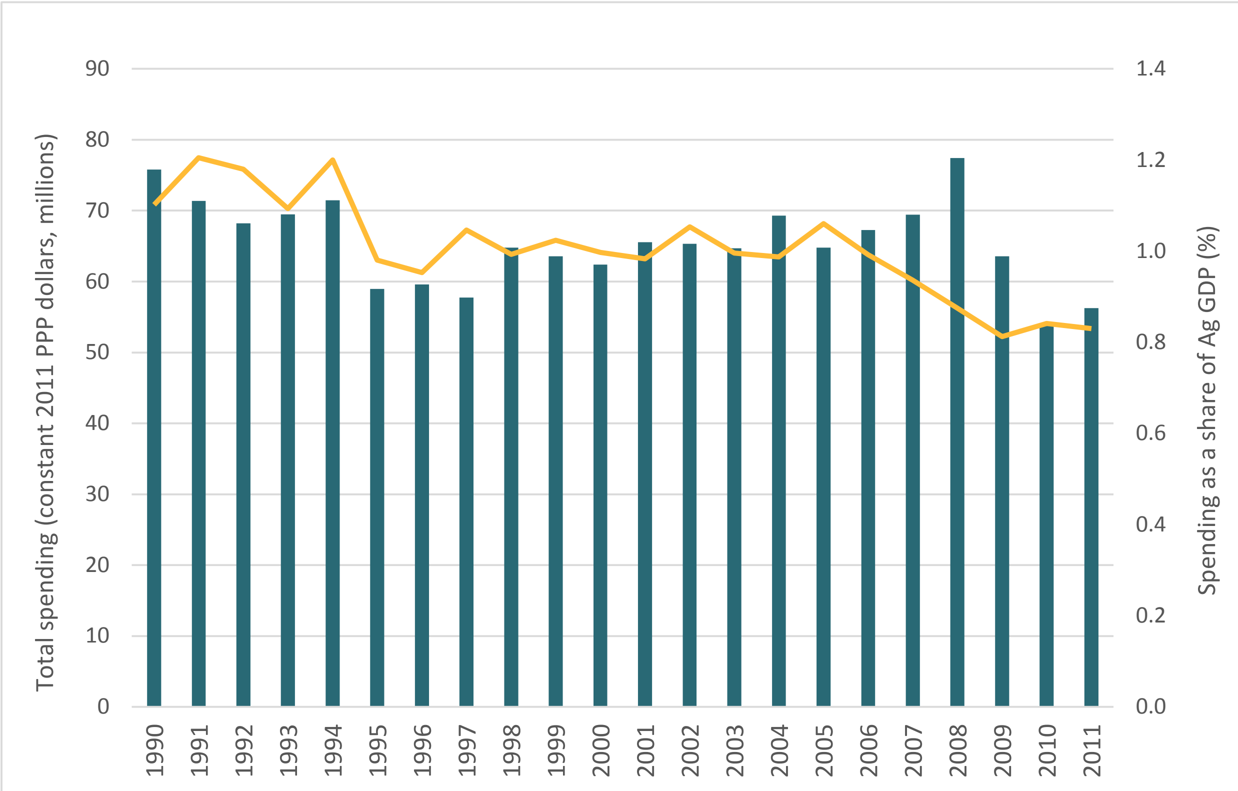
Figure 5: Top Agriculture Exports from Sub-Saharan Africa to Top Destinations



Note: Values represent average gross imports (millions of US dollars) from SSA countries for 2011-2014. Data (using HS1988/92 classification) on agricultural products are for: vegetable products including fruits, nuts, cereals, coffee, tea, oil seeds (section 2), animal and vegetable fats and oils (section 3), prepared foodstuffs and tobacco (section 4), and textiles (section 11).

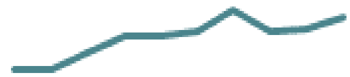
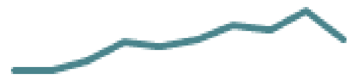
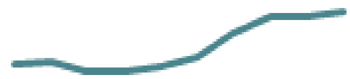
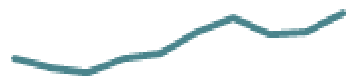
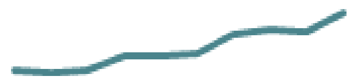
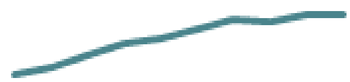
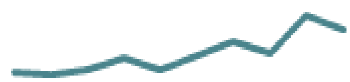
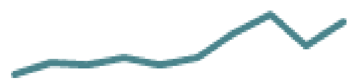
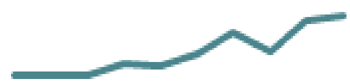
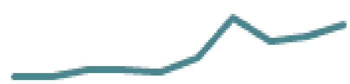
Source: UNCOMTRADE via World Integrated Trade Solution (WITS), retrieved February 2016.

Figure 6: Trends in Average Public Expenditure for Agriculture R&D in Sub-Saharan Africa, 1990-2011



Source: Agricultural Science and Technology Indicators database, retrieved February 2016.

Table 1: Top Destinations for SSA Agriculture Exports

Destination	3 year average 2012-2014	% growth 2005-2014	Trends 2005-2014
European Union	13,144,688	64%	
Intra-Africa	4,948,829	88%	
China	2,423,860	159%	
United States	1,868,513	67%	
India	1,604,259	254%	
Russia	992,413	205%	
Japan	803,643	49%	
Malaysia	803,136	504%	
Vietnam	680,857	1061%	
Indonesia	627,528	263%	

Note: Values represent average gross imports (millions of US dollars) from SSA countries for 2011-2014. Data (using HS1988/92 classification) on agricultural products are for: vegetable products including fruits, cereals, coffee, tea, oil seeds (section 2), animal and vegetable fats and oils (section 3), prepared foodstuffs and tobacco (section 4), and textiles (section 11).

Source: UNCOMTRADE via World Integrated Trade Solution (WITS), retrieved February 2016.

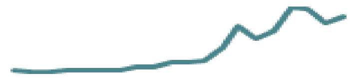
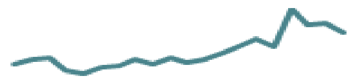
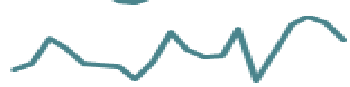
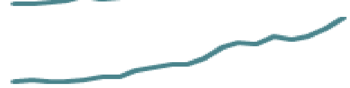
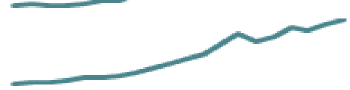
Table 2: Top SSA Exports of Agriculture Products

Exporter	3 year average 2012-2014	% growth 2005-2014	Trends 2005-2014
South Africa	7,023,378	73%	
Cote d'Ivoire	6,455,299	109%	
Ghana	3,548,217	179%	
Kenya	2,782,609	91%	
Ethiopia	1,730,526	198%	
Tanzania	1,495,617	191%	
Nigeria	1,268,585	120%	
Zimbabwe	1,248,001	84%	
Cameroon	1,187,908	67%	
Uganda	928,127	124%	

Note: Values represent average gross imports (millions of US dollars) from SSA countries for 2011-2014. Data (using HS1988/92 classification) on agricultural products are for: vegetable products including fruits, nuts, cereals, coffee, tea, oil seeds (section 2), animal and vegetable fats and oils (section 3), prepared foodstuffs and tobacco (section 4), and textiles (section 11).

Source: UNCOMTRADE via World Integrated Trade Solution (WITS), retrieved February 2016.

Table 3: Top Products in SSA Agriculture Exports

Product	3 year average 2012-2014	% growth 2005-2014	Trends 2005-2014
Cocoa	9,381,495	126%	
Fruits & nuts	6,474,738	100%	
Coffee, tea & spices	3,757,526	85%	
Tobacco	3,495,551	111%	
Cotton	2,403,402	11%	
Oil seeds	1,897,360	246%	
Sugars	1,820,694	28%	
Live trees & cut flowers	1,205,688	101%	
Fats & oils	1,141,256	171%	
Vegetables	1,120,426	143%	
Cereals	1,084,422	187%	

Note: Values represent average gross imports (millions of US dollars) from SSA countries for 2011-2014. Data (using HS1988/92 classification) on agricultural products are for: vegetable products including fruits, cereals, coffee, tea, oil seeds (section 2), animal and vegetable fats and oils (section 3), prepared foodstuffs and tobacco (section 4), and textiles (section 11).

Source: UNCOMTRADE via World Integrated Trade Solution (WITS), retrieved February 2016.