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Demonstrating the benefit of agricultural biotechnology in developing countries by bridging the public and private sectors

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Currently, hunger affects nearly 12 per cent of the world's population — 4 per cent more than in 2015, when the United Nations launched the 2030 Agenda for Sustainable Development. If all scientific knowledge and technological innovation in crop development were readily available and globally adopted, could zero hunger have been achieved by 2030? Most people recognize the potential for agricultural biotechnology to contribute to food security. However, there has been limited application and adoption of new crop varieties in countries that are disproportionately affected by malnutrition and food insecurity.

Applying science and technology to agriculture can increase crop yield and enhance nutrition; however, the potential of agricultural biotechnology (agbiotech) in developing countries has yet to be realized. Strict policy and liability, poor infrastructure, and low economic incentives for commercialization are obstacles to investment. Historically, the lack of improved varieties and soil and agronomy issues have contributed to poor yield, which has directly limited food availability in developing countries[1]. In regions where improved varieties have been adopted, crop production increased by 40 per cent over 20 years[2]. Although a desire to foster the application of science exists in the developing world, only 11 of 54 African countries have permitted the commercial release of crops derived from transgenic approaches[3]. In some instances, approvals have only been made for Bt cotton with little broader effect on agricultural productivity. For new advances in agbiotech, this number is even smaller. In December 2020, Nigeria became the first African country to authorize guidelines for developing and releasing gene-edited crops. Encouragingly, Kenya followed and the number of African countries considering similar proposals is increasing. To address the challenges and opportunities in the adoption of agbiotech products in developing countries, a diverse group from lower–middle to high-income countries — with majority representation from Africa, and including communicators, regulators, educators, farmers, consultants, for- and not-for-profit funders and founders, Fellows of the Royal Society and the Royal Society of Biology, and World Food Prize and Nobel laureates — convened at the Banbury Center, Cold Spring Harbour Laboratory. Five challenges were discussed that affect agbiotech innovation, from discovery to delivery and adoption in developing countries: (1) environmental (a lack of an enabling environment for sustainable research and development); (2) economical (a lack of business opportunities and incentives for national development, and incoherent regulatory landscape); (3) educational (a lack of capability and infrastructure building in grants); (4) connection (a lack of a network between stakeholders, researchers, farmers, educators, community leaders, government and policymakers); and (5) communication (a lack of public awareness, coupled with misinformation or disinformation).

Enabling sustainable environments for agbiotech innovation and adoption

International agbiotech research is severely underfunded; its main sources of funding come from international development agencies, governments, foundations, seed companies and venture capital. An enabling environment consists of a thriving value chain made up of vital public and private sectors, with adequate funding for maintained research facilities, trained staff, seed production, storage, distribution and sales, together with supportive governments with the political will and functional regulatory frameworks. This is the key to efficient and sustainable innovation, and the adoption of agbiotech. Regardless of the technology, basic infrastructure (such as irrigation, roads and storage facilities) is crucial and must be expanded upon or developed where needed. The lack of an enabling environment affects not only agbiotech innovation, but also its delivery and adoption.

Despite the enormous potential for agbiotech to solve agricultural problems and contribute to food security, there is a disconnect between innovative research and the delivery and/or adoption of developed products. Irrespective of the science, agbiotech or non-agbiotech applied in innovation, there is a prevalence of low or stagnant adoption of improved crop varieties in the rainfed ecosystems of Africa[4]. In the past decade, modern rice and maize varieties comprised more than 90 per cent of their crop area in Asia, but only 45 per cent in Africa[5]. This is mainly due to deficiencies in enabling environments and dimensions that could incentivize seed companies to invest and empower African farmers to access new technology and profit from its adoption. For

example, adoption rates of drought-tolerant maize varied from as little as 9 per cent in Ethiopia, Tanzania, Uganda, Malawi, Zambia and Zimbabwe to 69 per cent in Malawi[6]. Malawi had the highest adoption rate owing to its large-scale 'Farm Input Subsidy Program' (implemented in 2005–2006), in which fertilizer subsidies were made available to maize farmers. Uganda is following this path: strong dissemination efforts by seed companies and agricultural extension have recently improved adoption rates. Substantial barriers to adoption in Ethiopia, Tanzania, Uganda, Malawi, Zambia and Zimbabwe include a lack of improved seed information, limited financial resources, high seed costs and farmers' perception of the crop variety[6]. Achieving Africa's agricultural potential will require a substantial investment, including a sixfold increase in the effort to improve crop varieties, at least eight billion US dollars towards grain storage, 65 billion US dollars towards irrigation systems, and considerable improvements in other infrastructure and regional trade[7].

Economics, partnerships and the added-value chain

Weak returns on investment and unattractive risk–reward ratios are the most important hurdles in progress towards a real impact. When the economic effect of adoption is not well-perceived or reliable data on measurable gains are unavailable, the result is low confidence in the new technology. The lack of financial incentives limits private-sector participation, which is a major driving force for agribusinesses in the developing world as much as in the developed world. Farmers may lack access to improved varieties and other inputs, often because seed companies are not investing in them. Moving forward, the goal must be to build economic incentives to drive long-term investment adoption by consumers and growers, and an ecosystem of business around agbiotech and agricultural innovation more broadly. This can be advanced by publicizing the economic benefits at the individual and societal levels.

The Agricultural Biotechnology Program funded by the US Agency for International Development (USAID) Bureau for Resilience and Food Security manages more than 20 projects in 10 African countries, including the development of insect-resistant and drought-tolerant TELA maize; the development of pod-borer-resistant Bt cowpea; *Striga*-resistant sorghum; bacterial-wilt-resistant banana; and late-blight-resistant potato. Regional and international partnerships among stakeholders are critical for creating value, scaling and sustaining contributions from agbiotech. Such partnerships must be established along the value chain to promote innovation, delivery and adoption. Local partnerships among institutions of learning, government and regulatory agencies, and the private sector are crucial for framing sustainable agbiotech development strategies. Such strategies must be based on genuine market demand for valuable products, and must address the fundamental limitations in the value chain within a country. Yet, successful local innovations and production practices are not funded or scaled across the continent. The importance of regional and international partnerships in agbiotech cannot be overemphasized. Technologies for African Agricultural Transformation (TAAT) — promoted by the African Development Bank Group and implemented through the CGIAR system — provides resources to evaluate and improve the scaling readiness of products, and positions of proven technologies in country agricultural-development portfolios. TAAT currently operates in 22 African countries and focuses on nine priority crops (including maize, wheat and rice). The programme (which comprises six enabler compacts) addresses cross-cutting issues that include management, capacity development and policy support. The African Continental Free Trade Area (AfCFTA) has made strides toward harmonizing the market and regulations across the continent. Although the successes of past and current programmes are duly acknowledged, there is a need to build on these successes and introduce new paradigms to overcome weak delivery and adoption of crops derived from agbiotech.

Harmonizing the regulatory frameworks among member states in regional and international partnerships has yet to be explored. For example, there is limited partnership in agbiotech in trade among African countries, which results in difficulties in sharing developmental packages in trade among neighbours with similar needs. Thus, each country requires a custom-made technology package, which increases the overall investment cost and limits private-sector involvement. The harmonization of regulatory frameworks at the regional and — where possible — international levels is crucial to fostering strong partnerships for sustainable innovation, delivery and adoption of agbiotech products. To achieve this, national regulatory agencies must be enabled to act in concert in ways that span national borders. This harmonization would include regulatory policies and intellectual-property rights to foster lasting regional cohesion and impact. However, cross-border approaches to deregulation are not so easily implemented when dealing with multinational environments.

The varietal approval and release process can be cumbersome and take a decade or more in many developing countries. Many varieties are adapted to environments that cross national boundaries, as is the case for smaller countries — especially in Africa. Until recently, countries that wished to make varieties from neighbouring countries available to their farmers were required by law to replicate the entire approval and release process. In 2015, the seniormost agricultural officials from India, Bangladesh and Nepal agreed to accept rice varietal approval data for varieties that target cross-border homologous environments[8]. Similar agreements are under negotiation in eastern Africa and could serve as a foundation for broader acceptance of new agbiotech varieties.

Investing in capability- and resource-building

Agricultural research grants are often short term, and must incorporate long-term capability- and resource-building funding support. The behaviour and policies of science-funding organizations and governments drive research culture. These funding mechanisms often define success on the basis of short-term outcomes at the expense of long-term impact, such as capability building, development and infrastructure maintenance. As a result, these projects — although seemingly ambitious — often fall within a vicious cycle of short-sighted, superficial investments that do not create lasting impact. Project participants are trained in specific skills, such as molecular-breeding techniques. However, suitable employment opportunities are absent and many early-career investigators relocate to find appropriate employment opportunities and/or an enabling research environment elsewhere, thus contributing to the 'brain-drain' predicament faced by African scientists. This cycle continues when the next funding agency develops the next short-term project. To break this trend, granting agencies should consider long-term investments in capability-building and research-infrastructure sustainability, as much as the scientific goals put forward by principal investigators (especially if there is international collaboration). The combination of investment sustained over time and capacity development, including in responsible stewardship of the innovation, is a powerful one. Bt aubergine in Bangladesh and Bt cowpea in Nigeria are two prime examples of the benefits of a comprehensive approach. Provisional seed grants for startups and early-career researchers must be prioritized to sustain career development after

Table 1 | Communication efforts to support the impact of agbiotech in LMICs

Audience	Message	Communication	Outcomes and benefits
LMIC governments	Success stories, adding value to people and income potential	Case studies; engagement with local science experts and growers; field trials	Enhanced understanding of science; support for facilities and training; investment and job creation; rational regulatory policy harmonization
Growers in LMICs	Benefits for yield protection, profit	Demonstrations; field trials; extension	Demand; interest and lobbying for new varieties or products
Consumers in LMICs	Safety and value	Social radio	Adoption and demand for new products
Regional seed companies	Success stories for market and profit potential	Data and market size	New product offerings; building a sustainable value chain
Regional science centres and universities	Value of investing in training and novel business models	Case studies of student careers (for example, WACCI)	Enhanced scientific training and expert knowledge building for future professional activities
Funding agencies	Success stories of individual POCs and PPPs	Case studies of crops or regions	Further investment; focus on the sustainable, long-term impact of projects
Consumers in wealthy countries	Authentic narrative on urgent global food security needs	Case studies and personal accounts	Weaken anti-science agenda in the media and replace with positive examples

LMICs, low and middle-income countries; POCs, persons of concern; PPPs, public–private partnerships.

the research-funding period. New private-sector opportunities are also needed to drive the research and development enterprise. For example, the West African Center for Crop Improvement (WACCI) has demonstrated that trained doctoral-level researchers can go on to lead national breeding programmes in various countries within West Africa. Similarly, tropical legumes projects supported by Bill & Melinda Gates Foundation — coordinated by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) — strengthened breeding pipeline and seed delivery systems in legumes and created a next generation of scientists for agriculture in 13 African countries and 2 countries in Asia.

Consumer preference determines the effect of any scientific innovation through demand that drives its adoption rate. Unfortunately, there is a growing breakdown in trust between politicians, scientists and society[9], and there is a precedent for innovative agricultural products being targeted by misinformation or disinformation and scaremongering campaigns that negatively affect the perceptions of farmers and consumers[10]. For early-career scientists to communicate science effectively without compromising their research programmes and tenure, governments must support educational academic institutions as much as research and funding agencies must include support in their grants for training communicators. The benefits of agbiotech must be effectively communicated to each target audience in low and middle-income countries (Table 1). It is a complex and sensitive endeavour that requires effective strategies to engage various stakeholders, including farmers, policymakers, researchers and the general public. The successful communication of agbiotech in Africa should focus on education, transparency and collaboration.

Summary

The agricultural transformation of Brazil through soybean intensification in the Cerrado biome is the closest model that Africa could follow, given the similarities in land mass, shared biophysical constraints (especially soil), ecological diversity and low population density[11]. However, a single integrated market and regulatory environment must be created, and African scientists must lead the scientific innovation in Africa. Increased attention to soil health also bodes well for more-strategic public and private investments that could enhance the productivity of Africa's acid savannahs while also helping to reduce pressure on more-fragile woodland and forest regions. Lessons should also be learned from the underutilization of the Biosciences eastern and central Africa (BecA) and International Livestock Research Institute (ILRI) hub, which aimed to support African countries in developing and applying bioscience research with the goal of helping resource-poor farmers to improve productivity and increase income. Reliance on international donor support or help does not provide long-term sustainability.

We have identified five technically sound, administratively feasible and politically supportable opportunities for agbiotech delivery and adoption: (1) convince international and national funding agencies to sustain project gains after the funding period for long-term impact; (2) facilitate regional stakeholder cooperation through a return on investment, and harmonize the regulatory framework for agbiotech product development and growth; (3) develop interdisciplinary partnerships to align interests and incorporate training, development and resource management in collaborative grants; (4) use existing resources and products for validation, delivery and adoption; and (5) promote science advocacy within the community through communication by scientists and educators with students, community leaders and policymakers.

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Competing interests

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