ISSN: 2641-6379
World Journal of
Agriculture and Soil Science
DOI: 10.33552/WJASS.2021.07.000655
Iris Publishers

Research Article

Food Security in Africa: The Future of GMOs

Claudine Chegini and Andrew Schmitz*

Institute of Food and Agricultural Sciences, University of Florida, USA

***Corresponding author:** Andrew Schmitz, Institute of Food and Agricultural Sciences, University of Florida, USA.

Received Date: April 19, 2021

Published Date: May 12, 2021

Abstract

Despite numerous projects and collaborative efforts to implement genetically modified (GM) crop technology in Africa over the past 20 years, GM crops have struggled to maintain a foothold on the continent and rarely reach market approval or accessibility for small farmers. This is due to a number of reasons that include wavering consumer acceptability, hesitancy of large companies to invest in research and development (R&D), and the intricacies of cultural and historical land use in Africa.

With lower input costs and better returns to R&D, gene-editing (GE) technology offers a unique way forward for Africa's agricultural industry. If these new plant breeding techniques allow African countries to more prolifically adopt GE technology in the future, it will be important to tailor the approach to smaller scale targeted regions and work directly with smallholder farmers who produce the majority of food in Sub-Saharan Africa. Furthermore, concerning agricultural trade, consideration might be given to expanding food imports. Future investment could include improving local staple crop varieties, such as cassava, millet, sorghum, and bananas, which constitute a large portion of Sub-Saharan African diets in rural areas most affected by food insecurity.

Ultimately, forward momentum in adopting agricultural biotechnology in Africa must involve a cooperation between domestic, foreign, social, economic, political, and scientific partners. Participation and willingness from the private sector will be an integral factor not only in the R&D stages, but also in developing the infrastructure and value-chains to support production.

Keywords: Feed the Future African countries; Food security; GMOs

Introduction

Amidst the landscape of global food security lies the controversy of genetically modified (GM) and genetically engineered/genome edited (GE) technology and the potential returns to investment in research and development (R&D) in this area. While there are proven returns to investment in agricultural biotechnology R&D—especially in developing countries—Africa has prevaricated on the adoption of GM and GE crops.

There are various forms of crop breeding. Conventional breeding has been used for hundreds of years to slowly improve and select for certain traits. Agricultural biotechnology is a method introduced in the twentieth century to provide a breeding method for accelerating changes and introducing new traits in existing crops [1]. Genetically modified (GM) crops are marked by the evidence of a transgene (or cisgene) not originating from the plant or crop being modified. Genome editing (GE) allows for faster and more accurate development of new crop and plant traits without any genetic material from an external source [2].

This paper provides an overview of the possible reasons for the relatively slow rate of adoption of and wavering interest in agricultural biotechnology R&D investment in Africa. There are at least two major reasons for the slow adoption rate of GM food products and almost non-existent adoption of GE technology in Africa. First, some regions that trade with Africa, such as the European Union (EU), are unwilling to accept GM food products.

Second, there is reluctance by the private sector to create a value chain that provides for sufficient returns and allows for protection of agricultural intellectual property.

Scope of GM Crops and Genetic Engineering

There are various forms of crop breeding. Conventional breeding has been used for hundreds of years to slowly improve and select for certain traits. Agricultural biotechnology is a newer method of crop breeding. GM crops, introduced in the 1990s to accelerate changes and introduce new traits in existing crops, are marked by the evidence of a transgene (or cisgene) that does not originate from the plant or crop being modified. GE technology allows technology allows for faster and more accurate development of new crop and plant traits.

Less than 1% of the world crop acreage planted in GM crops is on the African continent. Of all the African countries that have approved GM food products, only South Africa (canola, maize, soybean, and rice); Sudan and Egypt (maize); Burkina Faso and Zambia (maize); Malawi and Nigeria (cotton, cowpea, maize, soybean); Ethiopia (cotton); Kenya (cotton); and Eswatini (cotton) have successfully brought GM varieties to market. Even those they do market are at low rates compared to the production of their global counterparts.

New plant breeding methods that utilize genome editing techniques, such as CRISPR cas-9 technology, are not considered GM technology and crop varieties produced using these methods are referred to as genetically engineered (GE) crops. Because this is a relatively new form of plant breeding, there are not many commercialized GE crops worldwide, and none currently used in Africa.

Compared to the rest of the world, Africa as a whole has lagged behind in adopting agricultural biotechnology. Of the existing economic partnerships in Africa, the Common Market for Eastern and Southern Africa (COMESA) has been the most successful at GM adoption. This is partly due to legislation passed in 2013 that allows for a group approval process for GM products. Through this legislation, if one-member country of the COMESA tests and approves a GM crop for the general market, then the other member countries need not complete the same testing and trials before approving the crop in their own country. This has saved time and financial capital and has allowed approval of GM crops at a much faster rate in COMESA member countries such as Egypt, Kenya, Nigeria, and Ethiopia.

Harsh & Smith [3], Schnurr [4], and Rock & Schurman [5] emphasize the importance of a case-by-case implementation evaluation before drawing broader conclusions on the impact of biotech adoption or conversely the potential losses and opportunity costs associated with non-adoption. In this context, globally, the privatization of R&D of agricultural biotechnology has substantially increased over time. Anderson et al. [6] argue that companies are incentivized to invest when the legal framework is in place for private entities to protect their intellectual property interests, as is the case with some seed varieties. In these instances, consequent private funding allows more flexibility for public funds to be used for R&D in areas where private firms are less inclined to invest.

Biotechnology Adoption

Increasing concentration in the seed industry has led to concerns about whether smallholder farmers in developing countries can afford the cost of either the biotechnology or the liability for violating intellectual property rights of large companies. Rock & Schurman [5] use Ghana as an example to present evidence of the complexity of private investment and the influence of multinational corporations and their subsidiaries over regional policy, decision making, and project continuation. They highlight the role of "broker organizations" and programs funded by entities such as the United States Agency for International Development (USAID), the Rockefeller Foundation, and the Gates Foundation. The African Agricultural Technology Foundation (AATF), created in 2001, was jointly established to facilitate public-private research and funding to aid in the introduction of biotechnology in Africa. Some might contend that the primary purpose of groups such as the AATF is to push a pro-GM agenda by creating the right climate for social, political, institutional, and small-producer acceptance of GM products along the supply chain from research to marketing. However, the inconsistent adoption of GM technology in Africa over time brings the role and efficacy of these programs within the scope of African culture into question. The introduction of GM technology in Africa has partially occurred amidst campaigns for land policy reform and land rights, which bring to the forefront both the economic and cultural importance of land, especially in rural areas, as a source of identity and heritage [7,8]. Indeed, much land in Sub-Saharan Africa is governed under customary tenure, including various forms of collective ownership and the potential for variable ownership across regions [9]. Some exploration of this cultural and collective view of land may help elucidate why pro-GM subsidiary organizations that are able to influence the passage of biosafety regulations with relative ease are struggling to implement plant patents and other intellectual property right laws in parts of Africa.

Property Rights and Privatization

Anderson et al. [6] state that the ability to legally protect agricultural intellectual property (such as seeds and other genetic material) is a main incentive for private companies to invest in developing countries. Without this guarantee, agricultural biotech companies are often hesitant or unwilling to lease their technology. Such is the case with a Monsanto-funded Bt cotton project in Ghana. Monsanto pulled out of the project when a Plant Breeders Bill failed to pass [5]. Upstarting trials of GM crops in many African countries not only encounter the risk of loss of funding, but also the loss of social capital and morale for the intellectual work contributed by local scientists and farmers.

That is not to imply that public funds should be used for projects with less importance or low returns to R&D. According to Kerr [10], reduced investment in R&D slows the rate of productivity improvements. If the rate of productivity improvement decelerates, it will be difficult to increase agricultural output to meet the food security challenges that will arise in the run-up to 2050. Within the scope of global food security, it is critical to increase investment in R&D, of which GM and GE crops are a large component. Kerr [10] also raises the point that the indirect effect of the trade issues surrounding GM foods may be more detrimental than the direct effect to food security in the long run. By having a significant proportion of the global market eschewing acceptance of GM technology and products, the potential market for those investing in the research and development of new GM products is smaller than it could be. This feeds back into the decisions of the firms contemplating those investments. As potential benefits are reduced, fewer avenues for research will exhibit the potential for positive returns on investment and, hence, will be funded [11]. As a result, the rate of increase in agricultural productivity is reduced. As suggested above, future food security depends upon improvements to agricultural productivity. The effect has been particularly investment-inhibiting for crops mainly grown in developing countries where there has been relatively limited investment [10].

Role of the European Union

Historically, African leaders and regulatory boards have been hesitant to approve first- and second-generation GM food products for human consumption. Some researchers argue that Africa's use of GM technology is intertwined with the European Union's strict regulations on GM food products. As a food export market for many African countries, EU consumer demand for non-GM food products has greatly deterred the implementation of GM crops in Africa. Part of this hesitancy is due to the Precautionary Principle used by the European Union to approve GM food products.

It is important to keep in mind that within the scope of exports from Africa as a whole, and especially Sub-Saharan Africa, agricultural commodities account for a minor percentage of both the value and volume of exports. Unlike crops such as tea, coffee, and cocoa, which the European Union imports worldwide, basic food crops important for global food security, such as wheat, corn, and rice, are not imported by the European Union from Africa. This raises the question as to the significance of the impact of GM regulations of the European Union on food security in Africa.

Adoption of GM Crops

Rock & Schurman [5] suggest that the ultimate adoption of GM crops in Africa will depend upon a complex interaction between domestic, foreign, social, economic, political, and scientific factors. Especially relevant is the participation of multinationals, public private partnerships, and foreign aid. They further emphasize the importance of contributions from external donors for projects that can require upward of 10 years in conjunction with the willingness of biotechnology companies to see that long-term commitments in Africa could be in their best interests. For such a symbiosis to occur, legal frameworks and returns to research that satisfy all parties must be put in place and maintained while simultaneously preserving public support, quelling opposition, and convincing farmers and local sellers that the GM crop variety is affordable, profitable, and safe. As Rock & Schurman [5] state, seldom is this complex choreography successfully achieved.

Along with recent increases in intra-African trade and the approval of the GM cowpea in Nigeria, many African countries are initiating field trials of other GM crops such as bananas and cassava [12-14]. With some trading partners more willing to accept GM products and a gradual positive shift of consumer and policymaker attitudes toward GMOs, Africa as a whole may begin to implement the use of more GM technology. Smallholder farmers in African countries, who provide a large share of the domestically consumed food, have experienced climate-related crop loss [15]. As they struggle to produce crops under current conditions, many of these smallholder farmers are beginning to warm to the idea of GM crop technology. Notably, Uganda has begun field trials for a GM banana [12]. Indeed, as Lakkakula et al. [16] state, as natural resources decrease, biotechnological methods for increasing agricultural productivity will help meet food security goals.

For companies to invest in biotechnology there must be some guarantee on the acceptability and safety of GM food products. For example, in the case of Golden Rice, consumers rejected the product even though the gains from Golden Rice could have been substantial. Javelosa [17] found that while potential returns to R&D in creating a GM rice variety could far outweigh the costs, the risk of failure on a scientific or marketing front could result in negative returns. Many argue that a GM rice variety may never be accepted as a basic food crop [6,14,18].

If consumers were to find a variety of GM rice acceptable, Lakkakula et al. [16] find that the introduction of a GM rice variety that increases global yield by 5% could result in both a consumer gain of US$23.4 billion to US$74.8 billion and a producer loss of US$9.7 billion to US$63.7 billion worldwide. The estimated net gain to society would be US$11.1 billion to US$13.7 billion. Overall, they find a positive economic surplus for major exporters and importers of rice based on a 5% supply increase with a GM rice variety. Additionally, the adoption of GM or GE rice varieties would have a far greater impact on rice prices for poorer counties than for richer countries. In 2020, Africa imported 40% of rice consumed on the continent [19].

Food insecurity is a global issue, especially in Sub-Saharan Africa. When considering public investment in Africa, the focus should be more on basic food crops, such as cassava, rather than on export goods, such as coffee [14]. For example, in Uganda, where the rate of return to R&D in cassava cultivation (both GM and non-GM) is extremely high, expanding the supply of cassava with investments directed toward increasing production (such as expanding the use of GM cassava) results in increases in both consumer and producer welfare [13].

Domestic consumption, production, import, and export data (Tables 1-3; [19]) of staple carbohydrate crops for Feed the Future African countries may help support a similar conclusion. Of all African countries that reported domestic consumption of rice in 2020, 40% of total rice consumed was imported. For only Feed the Future African (FTFA) countries, 40% of total rice consumed in 2020 was imported. For 2020, 65% of total wheat consumed in Africa was imported and 69% of wheat consumed in FTFA countries was imported. When looking at maize production and consumption in 2020, Africa imported 23% of maize consumed while FTFA countries imported only 3% of maize consumed. Compared to millet and sorghum, import share of domestic consumption was below 1% in 2020. As such, more attention should be given to future investments in African agriculture for increasing production efficiency of domestically produced staple crops, such as cassava, millet, and sorghum.

Table 1: Wheat: Feed the Future African Countries, Consumption, Production, Imports, Exports (1000 Tonnes), for Selected Years, 2010-2020*.

Wheat	Year	Consumption (1000 tonnes)	Production (1000 tonnes)	Imports (1000 tonnes)	Exports (1000 tonnes)
Ethiopia	2010	3715	2860	700	0
	2015	6800	4651	2900	0
	2020	6700	5300	1500	0
Ghana	2010	450	0	467	18
	2015	610	0	788	91
	2020	825	0	980	150
Kenya	2010	1450	256	818	8
	2015	1850	239	1634	42
	2020	2600	300	2200	10
Mail	2010	188	24	164	0
	2015	345	36	324	0
	2020	430	40	400	0
Niger	2010	255	0	255	0
	2015	205	0	205	0
	2020	230	0	230	0
Nigeria	2010	3582	100	4052	570
	2015	4070	60	4410	400
	2020	4760	60	5100	400
Senegal	2010	415	0	403	21
	2015	600	0	621	23
	2020	680	0	725	25
Uganda	2010	131	20	111	0
	2015	281	22	259	0
	2020	530	20	500	0

Data Source: USDA-FAS 2021

*FTFA countries not reporting data some/all years.

Table 2: Rice: Feed the Future African Countries, Consumption, Production, Imports, Exports (1000 Tonnes), for Selected Years, 2010-2020*.

Data Source: USDA-FAS 2021

Rice	Year	Consumption (1000 tonnes)	Production (1000 tonnes)	Imports (1000 tones)	Exports (1000 tonnes)
Ethiopia	2010	0	0	0	0
	2015	391	91	300	0
	2020	661	91	570	0

Ghana	2010	790	295	580	0
	2015	1050	443	610	0
	2020	1550	575	950	0
Kenya	2010	390	57	305	10
	2015	570	77	490	0
	2020	730	80	650	0
Mali	2010	1000	842	80	0
	2015	1750	1515	170	0
	2020	2500	2150	300	0
Niger	2010	311	66	245	0
	2015	311	61	250	0
	2020	475	75	400	0
Nigeria	2010	4800	2818	2400	0
	2015	6400	3941	2100	0
	2020	6700	4725	1800	0
Senegal	2010	1131	411	775	22
	2015	1650	616	1020	10
	2020	1950	789	1175	10
Uganda	2010	182	142	80	40
	2015	194	154	40	0
	2020	246	166	90	10

*FTFA countries not reporting data some/all years.

Table 3: Maize: Feed the Future African Countries, Consumption, Production, Imports, Exports (1000 Tonnes), for Selected Years, 2010-2020*

Data Source: USDA-FAS 2021

Maize	Year	Consumption (1000 tonnes)	Production (1000 tonnes)	Imports (1000 tonnes)	Exports (1000 tonnes)
Ethiopia	2010	4650	4895	0	65
	2015	7900	7882	2	0
	2020	8600	8600	3	0
Ghana	2010	1800	1872	5	8
	2015	1800	1692	91	0
	2020	2950	2760	20	5
Kenya	2010	3450	3465	100	9
	2015	4150	3825	300	3
	2020	4400	4000	400	5
Mali	2010	1500	1404	5	5
	2015	2000	2276	0	0
	2020	3700	3500	0	0
Nigeria	2010	7600	7677	100	100
	2015	10600	10562	200	200
	2020	11800	11500	500	100
Senegal	2010	250	187	58	2
	2015	520	304	218	0
	2020	630	350	250	0
Uganda	2010	2200	2374	5	100
	2015	2500	2647	5	100
	2020	2650	2800	5	100

*FTFA countries not reporting data some/all years.

Historically, agriculture in Sub-Saharan African countries has trended toward goals of self-sufficiency in production in order to meet domestic consumption demands. A complex array of factors influences domestic production and consumption levels. These factors include climate, poverty, ease of access, urbanization and demographic shifts, changing dietary patterns and food demand, and the political landscape that help determine whether a certain country can increase its food self-sufficiency. Conversely, some of these factors also help determine the ability of a country to increase imports in order to compensate for production levels that are unable to meet domestic consumption [20]. In these cases, while increasing imports may reduce self-sufficiency, overall food security may be increased.

Furthermore, GM crops not produced directly for food or feed can have a positive impact on general food security. Qaim & Kouser [21] show that increased crop yields from the adoption of Bt cotton increases farm household income, which indirectly reduces food insecurity by almost 20%.

Genome Editing

More recently, genome-editing mechanisms that use site-specific gene editing, such as the CRISPR cas-9 technology, allow advances in plant breeding and agricultural development. Compared to the development of GM varieties, GE technology allows for faster development, leading to increased supply chain efficiency in taking a product from field trials to approval for the general market. The European Union has passed legislation that requires new GE products be treated in the same manner as GM products and to go through the same approval process. However, this regulation presents problems because it is much more difficult, and sometimes impossible, to differentiate a GE product from a conventionally grown product. This is because unlike GM goods that can contain evidence of a transgene, GE products contain no foreign genetic material. Countries such as Australia, New Zealand, and India are still in the process of determining how GE products will be regulated. Argentina has passed legislation that is specific to New Plant Breeding Techniques. Canada and the United States will regulate GE products on a case-by-case basis in the same manner as GM products. If reconsideration of regulations on on GE agricultural products results in a less stringent regulatory process in some countries, this may open the door for such products to begin testing in Africa. One of the major barriers to GM technology in African agriculture is the concern over losing trading partners and export markets. If some of the trade partners would choose to regulate GE products differently from GM products, that may present an opportunity for Africa to accrue the benefits of new plant technology while not incurring the risk of losing export markets associated with GM adoption. Bullock et al. [22] find that for a wide range of trait values in gene-edited versus transgenic crops, GE crops required a 96% smaller market area to break even on the financial investment for the same trait value per acre. The primary driver of the difference in break-even acreage between GE versus GM crops in their study was the increased probability of success for gene editing in the initial discovery portion of R&D.

With lower input costs and better returns to R&D, CRISPR and other GE technologies offer a unique way forward for Africa's agricultural industry. Indeed, if development of new crops can occur with less investment requirements, this may simplify the path toward implementing new crop varieties, particularly if private companies can simultaneously create a functional supply chain infrastructure for product dissemination. Less capital input requirements and/or a better return on investment (ROI) to R&D could allow public funds to be used toward farmer education and supply chain infrastructure.

Diet and Nutrition

Daily diets vary throughout the African continent [23]. Renzaho & Burns [24] present a comprehensive list of the main foods consumed in Sub-Saharan Africa. Like other regions of the world, urban populations consume less staple carbohydrates and more fresh fruits, vegetables, animal products, and fats and oils when compared to rural populations. Overall, the traditional African diet (Figure 1) can fulfill nutritional requirements if the quality and quantity of food consumption is adequate.

Figure 1: The African Heritage Diet Pyramid.
Source: Oldways Preservation and Exchange Trust (2011).

In the scope of developing and implementing new GM and GE varieties to increase food security in Sub-Saharan Africa, it would be relevant to develop improvements that increase production efficiency in crops that are already widely consumed in rural areas, which are more heavily impacted by food insecurity. Furthermore, demand for some crops, such as corn, rice, and wheat, is already readily supplemented by imports (Tables 1-3). However, domestic production of crops such as millet and sorghum, which are widely consumed in rural areas [24], are currently not heavily supported by imports. As such, future investments that attempt to increase levels of food security could explore development of a GM or GE variety of millet or sorghum.

Climate Change

There seems to be some agreement that climate is changing due to rising temperatures that cause drought and flooding on a global scale. This has created a dire situation in some areas of the world. This is especially true for equatorial and desert regions in Africa when compared to temperate regions such as Canada's plains. The 2018/19 growing season in Zambia was marked by extreme drought, which affected 2.3 million people [15]. Drawing from work by Ortiz-Bobea et al. [25], changing weather patterns and extreme heat have had a negative impact on food security in Africa due to reduced crop yields. In this context, the introduction and use of drought-tolerant GM or GE crop varieties could be crucial to maintaining a certain level of production. Other GM or GE varieties that increase yields can also help stabilize production by offsetting losses due to inclement weather. As such, GM and GE crop technology could be a component of Climate Smart Agriculture, which might be helpful in dealing with the impacts from climate change [26].

Feed the Future African Countries

The United States focuses considerable attention through USAID on the Feed the Future African (FTFA) countries: Ethiopia, Ghana, Kenya, Mali, Niger, Nigeria, Senegal, and Uganda. With respect to food security, Kennedy et al. [27] and van Kooten et al. [28] show theoretical results of improved food security when imports are combined with storage. While the theory is of interest, the extent to which these countries carry out storage without trade is unknown.

Both wheat and rice constitute a large percentage of grain imports for these countries. For FTFA countries, 69% total of wheat and 40% of total rice consumed in 2020 were imported (Tables 1 & 2). However, for maize production and consumption in 2020 (Table 3), FTFA countries imported only 3% of maize consumed. No FTFA countries yet have approval for cultivation of GM maize, although many of them are currently in field trials. Compared to millet and sorghum, import share of domestic consumption was below 1% in 2020. Taking these numbers into account, more attention should be given to future investments in African agriculture for increasing production efficiency of domestically produced staple crops, such as cassava, millet, and sorghum.

Conclusion

Despite numerous projects and collaborative efforts to implement GM technology in Africa over the past 20 years, GMOs have struggled to maintain a foothold on the continent and rarely reach market approval or accessibility for smallholder farmers. As long as conflicts and instabilities persist in funding, project partnership, seed dissemination, and intellectual property ownership, African countries will continue to fall short of bringing GM varieties through the full process of development, field trials, and approval. For those projects that do manage to bring GM varieties through the full approval process, organized consumer activism and general distrust of GM products, both globally and within many African countries, will continue under the Precautionary Principle stance of the main trading partners in the European Union. Even in the face of significant potential benefits in the scope of agricultural sustainability and food security, shifting consumer preferences for non-GM items could prove to be an additional obstacle to GM adoption at best or insurmountable to overcome at worst. Perhaps then, gene-editing technology and new plant breeding techniques can offer a new direction for African agriculture. With reduced input requirements, increased ROI, and better efficiency in the development stages, CRISPR cas-9 methods present the possibility of new crop varietals designed specifically for African farms. If private companies are willing to invest and there is less global consumer opposition to GE food products than to GM products, then many African countries could see similar benefits to implementing GM varieties without undertaking as much risk.

As discussed above, opposition to the adoption of GM technology comes from many sources. In addition, other issues to wide-scale adoption include marketplace labeling and marketing [29] and public support [30]. For example, the game theory approach developed by Schmitz & Smith [30] on consumer perception of GM and GE products demonstrates that anti-GM groups receive more positive media coverage than do pro-GM groups. From a rent-seeking perspective, the payoff for pro-GM lobbyists appears to be much less than for anti-GM lobbyists [29].

If African countries can more prolifically adopt GM or GE technology in the future, it will be important to design some varieties specifically for targeted regions. While Bt cotton has been planted with relative success in multiple agricultural regions, other GM varieties have struggled to take hold due to incompatibility with geography, soil, and African cultural styles of farming. This is contrary to countries such as the United States and Canada that have large-scale monoculture plantings of GM crops. In addition, improving the quality of seed, fertilizer, and other chemicals used by African farmers is necessary.

When technology adoption is viewed in the context of value-chain analysis, the role of future investment by the private sector becomes very important [2,6,18,31,32]. The private sector has proven to be more effective than the public sector in dealing with disruptions in many areas of the value chain. This would be helpful for developing countries that often do not have a well-integrated value-chain infrastructure.

With the rising population growth worldwide, although GM and GE technology present the potential for growth in agricultural production there is no consensus on whether agricultural productivity growth can keep pace with the increase in world population [29,33-36].

Acknowledgment

The authors wish to acknowledge the editorial comments of Carol Fountain and Abra Gibson.

Conflict of Interest

No conflict of interest.

References

1. International Service for the Acquisition of Agri-biotech Applications [ISAAA] (2019) Global Status of Commercialized Biotech/GM Crops in 2019: Biotech Crops Drive Socio-Economic Development and Sustainable Environment in the New Frontier. ISAAA Brief No. 55-2019. ISAAA, Ithaca, NY.
2. Schmitz A, Moss C, Schmitz T, van Kooten GC (2021) Agricultural, Trade, and Food Policy: Agribusiness, and Rent-Seeking Behaviour, 3rd edition. Toronto, ON, University of Toronto Press (forthcoming).
3. Harsh M, Smith J (2007) Technology, governance and place: Situating biotechnology in Kenya. Science and Public Policy 34(4): 251-260.
4. Schnurr MA (2012) Inventing Makhathini: Creating a prototype for the dissemination of genetically modified crops into Africa. Geoforum 43(4): 784-792.
5. Rock J, Schurman R (2020) The complex choreography of agricultural biotechnology in Africa. African Affairs 119(477): 499-525.
6. Anderson JR, Birner R, Nagarajan L, Naseem A, Pray CE (2021) Private agricultural R&D: Do the poor benefit? Journal of Agricultural & Industrial Organization 19(1): 3-14.
7. Odeny M (2013) Improving access to land and strengthening women's land rights in Africa. World Bank Conference on Land and Poverty. The World Bank, Washington DC.

8. Akinyemi BE, Mushunje A (2019) Landownership and usage for agriculture: Empirical evidence from South African Living Conditions Survey. Cogent Social Sciences 5: 166391.
9. Chimhowu A (2019) The 'new' African customary land tenure. Characteristic, features, and policy implications of a new paradigm. Land Use Policy 81: 897-903.
10. Kerr W (2017) Genomics, international trade, and food security. Estey Journal of International Law and Trade Policy 18(2): 53-77.
11. Kerr W, Yampoin R (2000) Adoption of biotechnology in Thailand and the threat of intellectual property piracy. Canadian Journal of Agricultural Economics 48(4): 597-606.
12. Kikulwe E, Birol E, Wesseler J, Falck-Zepeda J (2011) A latent class approach to investigating demand for genetically modified banana in Uganda. Agricultural Economics 42: 547-560.
13. Moss CB, Schmitz A (2019) Distribution of agricultural productivity gains in selected feed the future African countries. Journal of Agribusiness in Developing and Emerging Economics 9(1):78-90.
14. Moss CB, Schmitz A (2021) Distributional weights in benefit-cost analysis: Examples from Feed-the-Future countries. Journal of Agricultural & Industrial Organization 19(1): 15-24.
15. Sikapizye L (2020) African Farmers Yearn for Biotechnology in the Face of Climate Change. Cornell Alliance for Science, Ithaca, NY.
16. Lakkakula P, Haynes DJ, Schmitz TG (2015) Genetic engineering and food security: A welfare economics perspective. In Schmitz, A, Kennedy, PL, Schmitz, TG (Eds), Food Security in an Uncertain World, Volume 15. Emerald Group Publishing, Bingley, UK, pp. 179-193.
17. Javelosa JC (2006) Measuring the potential payoffs from biofortication: The case of high-iron rice in the Philippines. PhD dissertation, University of Florida.
18. Post L, Schmitz A, Issa T, Oehmke J (2021) Enabling environment for private sector investment: Impact on food security and poverty. Journal of Agricultural & Industrial Organization 19(1): 25-38.
19. USDA-FAS (2021) Rice Statistics. USDA-FAS, Washington, DC.
20. Luan Y, Cui X, Ferrat M (2013) Historical trends of food self-sufficiency in Africa. Food Security 5: 494-405.
21. Qaim M, Kouser S (2013) Genetically modified crops and food security. PLOS ONE 8(6): e64879.
22. Bullock DW, Wilson WW, Neadeau J (2021) Gene editing versus genetic modification in the research and development of new crop traits: An economic comparison. American Journal of Agricultural Economics (forthcoming).
23. Mbombo-Dweba TP, Mbajiorgu CA, Agyepong AO, Ogutta JW (2017) Food consumption patterns of Sub-Saharan African immigrants residing in Gauteng Province, South Africa. Applied Ecology and Environmental Research 15(4): 1023-1038.
24. Renzaho AMN, Burns C (2006) Post-migration food habits of Sub-Saharan African migrants in Victoria: A cross-sectional study. Nutrition & Dietetics 63: 81-102.
25. Ortiz-Bobea A, Ault TR, Carrillo CM, Chambers RG, Lobell DB (2021) Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change 11: 306-312.
26. Zilberman D, Wesseler J, Schmitz A, Gordon B (2019) Economics of agricultural biotechnology. In G.L. Cramer, K.P. Paudel, and A. Schmitz (Eds.), The Routledge Handbook of Agricultural Economics, Chapter 36. Routledge Publishers, London, UK, pp. 670-686.
27. Kennedy PL, Schmitz A, van Kooten GC (2020) The role of storage and trade in food security: Evidence from India. Journal of Agricultural & Food Industrial Organization 18: 0056.
28. van Kooten, GC, Schmitz A, Kennedy PL (2020) Is commodity storage an option for enhancing food security in developing countries? Journal of Agricultural & Food Industrial Organization 18: 0054.
29. Chegini C, Schmitz A (2021) GMOs: Past & Future. Journal of Biotechnology & Bioresearch 2(5). Forthcoming.
30. Schmitz T, Smith M (2020) Spinning the facts against genetically engineered foods? Theoretical Economics Letters 10: 458-480.
31. Nsabimana A, Niyitanga F, Weatherspoon D, Naseem A (2021) Land policy and food prices: Evidence from a land consolidation program in Rwanda. Journal of Agricultural & Industrial Organization 19(1): 63-73.
32. Weatherspoon DD, Miller SR, Niyitanga F, Weatherspoon LJ, Oehmke, J (2021) Rwanda's commercialization of smallholder agriculture: Implications for rural food production and household food choices. Journal of Agricultural & Industrial Organization 19(1): 51-73.
33. Schmitz A, Kennedy PL, Schmitz TG (2015) Food Security in an Uncertain World: An International Perspective, Volume 15. Emerald Group Publishing, Bingley, UK.
34. Schmitz A, Kennedy PL, Schmitz TG, editors (2016) Food Security in an Uncertain World: An Individual Country Perspective, Volume 16. Bingley, UK: Emerald Group Publishing, Bingley, UK.
35. Schmitz A, Kennedy PL, Schmitz TG (2017). World Agricultural Resources and Food Security, Volume 17. Emerald Group Publishing, Bingley, UK.
36. Kennedy PL (2019) Advancement in the economics of food security. In GL Cramer, KP Paudel, and A Schmitz (Eds), The Routledge Handbook of Agricultural Economics, Chapter 11. Routledge Publishers, London, UK. pp. 175-188.