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RESEARCH ARTICLE

The future is only the beginning

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Recent advancements in genome editing have captured the attention of scientists and policymakers, who contend that the technology has a large role to play in advancing food and climate security on the African continent. However, the modest results of earlier generations of biotechnology—such as genetically modified (GM) crops—raise questions about the sustainability of new technological interventions. This special feature examines lessons learned from previous generations of GM crops and other agricultural technologies, using them to analyze the portfolio of gene edited crops being developed for African farmers today. In this article, we introduce the 6 papers that make up the special feature by way of examining future-oriented discourses around the advancement of genome editing. Drawing on Science and Technology Studies, political ecology, and critical development studies, this introduction highlights the crucial factors that shape technology development, agricultural practice, and the politics of knowing and emphasizes the need to look toward multiple, diverse futures.

Keywords: Genome editing, Africa, Futures, Agriculture, Technology, CRISPR-Cas

In a 2023 *Nature* article entitled *CRISPR Technology: A Decade of Genome Editing Is Only the Beginning*, Joy Y. Wang and Nobel Laureate Jennifer A. Doudna reflect on recent advancements of genome editing, outlining what they see as the technology's most likely future trajectory. They anticipate short-term (the "near future") and long-term possibilities ("the more distant future"), musing that we should soon reach a stage where "CRISPR may be routinely used to generate disease-resistant, high-yield crops to increase global food supply and security" (Wang and Doudna, 2023).

Genome editing's potential utility in agriculture, while still in its infancy, has attracted the attention of scientists, philanthropists, and development professionals, among others. Like Wang and Doudna, many of these experts remain confident that genome editing will accelerate and advance plant breeding capabilities beyond what is currently possible with existing platforms. To this end, genome editing is presented as more precise, easier to use, and more accessible than earlier, "laborious" technologies used in plant breeding such as recombinant DNA (Tripathi et al., 2022; Wang and Doudna, 2023). CRISPR[1] and other genome editing tools, some argue, will "help feed future generations" (Innovative Genomics Institute, 2024).

To be sure, the idea of "the future" is alluring. The future is at once an amorphous temporal lens, as well as a goal toward which one constantly strives; it is always on the horizon. The future can be used to fundraise, to build support, and to invoke fear. In other words, the future is something to be performed: "future-oriented discourses, practices, and materialities shape the way society makes sense of science and technology, adjust how actors create strategies, and contribute to the shaping of technologies, as well as the development of entire technology fields" (Konrad et al., 2016, p. 469; see also Borup et al., 2006; Jansen and Gupta, 2009).

As scholars in Science and Technology Studies (STS) have long argued, promissory futures—such as those that underscore current narratives of genome editing—obfuscate the past, the present, and all the empirical messiness contained therein. Settling within this messiness may very well reveal factors and intersections that challenge linear notions of temporality and technology's development and uptake. Colonial histories of technological improvement, racial capitalism, heteropatriarchy, and imperialism all shape the agricultural practices, ecologies, governance, and epistemologies within which food futures are conceived. Scholars writing from within political ecology, critical agronomy, geography, and beyond have shown how

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1. CRISPR-Cas9 stands for Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-Associated9 system. In this article, we use "CRISPR" and "CRISPR-Cas" interchangeably with CRISPR-Cas9 for legibility, while noting that many Cas variants exist and comprise the wider genome editing toolkit.

essential these empirics are to understanding and dissecting the past, present, *and* future of plant breeding (Montenegro de Wit, 2017; Aga, 2021; Curry, 2022).

This special feature resists the temptation to obscure either the past or the present by scrutinizing the potential agricultural impacts of genome editing in sub-Saharan Africa. Within the imaginary of genome editing, the continent is a place of particular geographic importance, described by many as "uniquely poised" to benefit from this technology (Karavolias, 2021, para. 6; see also Mudziwapasi et al., 2018). It also has been referred to as the final frontier for capitalist expansion more broadly, and biotechnology specifically (cf. Rock, 2022; Eddens, 2024). Our special feature comprises authors from diverse disciplinary backgrounds (including across the biophysical and social sciences) and diverse institutional affiliations (including university and CGIAR[2] researchers). The papers that make up this feature take seriously the possibilities many say genome editing offers, while anchoring these optimistic claims within political, economic, historic, and agronomic realities of existing farming systems. These dynamics, so often obscured by future-oriented narratives, will shape the technology's uses and users in the years to come.

In the following sections, we explore how expectations embedded in promissory futures underlie existing narratives around genome editing's agricultural applications. Our goal is not to dismiss the future of agriculture (after all, it is the future!) but rather to interrogate how the future is utilized as a world-making device. In the essay's final section, we introduce the 6 papers that comprise this special feature. As a collection, the papers are thematically and geographically broad, encompassing the history and ongoing development of plant breeding and agricultural technologies on the African continent. We believe this diversity of subjects and insights helps to lay the analytical groundwork for discussing alternative futures.

"Make the impossible happen"

As genome editing has matured over the past decade, so too has the dominant narrative accompanying its release. This account, which is pervasive within academic writing and media coverage of the technology, describes genome editing as revolutionary (Barrangou, 2023) and as a means of democratizing breeding technologies (Mollins, 2017; cf. Montenegro de Wit, 2020). Central to this narrative are the *potential* benefits and/or ideas regarding what the technology *could* do. Some of those hypotheticals, especially as they relate to smallholder agriculture, are observable in the following synthesis written by CGIAR plant breeders:

> *While not a panacea, genome-editing technologies are widely accessible and could help democratize the benefits of science. Because they are relatively inexpensive to implement, they are being used to diversify agricultural systems and improve major and minor crops . . . . The widespread accessibility of genome-editing technologies means that they can be used by public sector institutions, including the Consultative Group for International Agricultural Research (CGIAR), to develop public goods that are unattractive to the profit-driven private sector, and to bring the benefits of genome editing to smallholder farmers.* (Pixley et al., 2022, p. 364)

The example of the African Plant Breeding Academy (AfPBA) offers an instructive case of this narrative in action. Convened in Nairobi in early 2023, the AfPBA was a 6-week CRISPR training program that brought together 11 scientists from 7 African countries. The goal of the program was to "train molecular scientists engaged in crop improvement, particularly those working in national programs at institutions desiring to implement or initiate gene editing programs" (UC Davis, 2023). Program participants hailed from countries whose regulatory regimes were either "relaxed" with respect to genome-edited crops—such as Nigeria and Kenya—or countries that were "looking to formulate separate rules for genome-edited plants and genetically modified organisms" (Nordling, 2023, p. 166). Countries were targeted to ensure that participants could "continue their work at home" (Nordling, 2023, p. 166).

Program participants received technical training, mentorship from experts, support in the form of equipment, and, crucially, access to a "CRISPR-Cas9 license" from the International Institute of Tropical Agriculture (IITA; Nordling, 2023, p. 166). IITA hosted the event, along with the African Orphan Crops Consortium, the University of California-Davis, and the Innovative Genomic Institute, while Bayer, Syngenta, the Foundation for Food and Agricultural Research, and the Mohammed VI Polytechnic University provided funding (Nordling, 2023, pp. 165–166). The AfPBA, therefore, provides insight into how some envisage, narrate, and dedicate resources toward the use of CRISPR for plant breeding on the African continent.

In addition to offering hands-on instruction, the course served as a training of trainers. One course instructor described this effort as a means of democratizing CRISPR: "These people will return to their national labs and do capacity building, and I think that that [sic] is a sustainable model for the democratization of this technology" (Nordling, 2023, p. 165). Coordinators hoped the course would produce cascading effects: "CRISPR is a key strategy toward improving food nutrition in Africa and the trainees from this program will be the change agents that will make the impossible happen" (Innovative Genomics Institute, 2023). While it's unclear what "the impossible" refers to here, course convenors shared high expectations of future results: "it's a step in the right direction . . . Improving skillsets through such a program is key to improving food security on the continent and an important contribution to a productive and sustainable transformation of African agriculture" (Innovative Genomics Institute, 2023). "The future of CRISPR," read one PowerPoint training slide, "belongs to you" (Henderson, 2023).

These snippets of quotes from AfPBA organizers and instructors resonate with the extended quotation from

2. The CGIAR, formerly known as the Consultative Group on International Agricultural Research, is an international network of research organizations.

Pixley et al. (2022) included at the beginning of this section. CRISPR is heralded as accessible (especially by public institutions), democratized, and a tool to benefit smallholder farmers. A "step in the right direction" and "transformation," along with making "the impossible happen," are temporal markers, indicative of the forward-looking narrative underpinning genome editing's advance. The speakers highlight ambitious benefits for food security, nutrition, and the agricultural transformation of an entire continent. These statements are grounded in *expectations*. Expectations can be understood as "the state of looking forward" and "real-time representations of future technological situations and capabilities" (Borup et al., 2006, p. 286), which can be used to mobilize resources (Borup et al., 2006), sway decision-makers (van Lente, 2012), and buoy public support (Lindberg et al., 2023). Expectations can be mistaken for imperatives; statements about what might occur evolve into normative requirements about what *should* occur (van Lente and Rip, 1998). Importantly, because expectation-laden discourses are built around what might happen in the future, they are often devoid of present political economic realities (Rajan, 2006).

The AfPBA, for instance, had an end-goal of training public-sector scientists interested in using genome editing for plant improvement. To that end, it focused on building access along some fronts, including knowledge building, technological training, and the provision of material and institutional resources (at the time of the training). But several other issues of access were left unaddressed. Consider, for example, the question of licensing. The AfPBA course was built on the expectation that graduates would return to their home institutions to utilize CRISPR alongside other skills gained. However, this foundational component of the organizers' theory of change was contingent on participants accessing funding and licensed technology on their own: "in the course," one organizer explained, "participants [used] IITA's CRISPR-Cas9 license, but back home they will need to make their own arrangements" (Nordling, 2023, p. 166).

It's not entirely clear why participants would be unable to use IITA's license after the completion of the program. This uncertainty stems, in part, from ambiguity around the license's terms and the specific use rights it grants.[3] Licenses are essentially legal contracts that allow licensees to use a patented invention. IITA may have received a license to use CRISPR-Cas in its own research and educational work but cannot extend these rights to work done outside of IITA. Or perhaps the challenge is with the scope of the license in terms of applications: If IITA's license is for noncommercial use, then AfPBA participants who intend to commercialize their work would need to seek alternative licensing arrangements.

Without more information, it's difficult to fully assess why the license used during the academy was not available to participants afterward. But this lack of clarity—and lack of available license post-academy—confounds narratives around genome editing's accessibility.[4] It is also unclear whether the training addressed issues of decision-making—that is, whether, why, and for what purpose genome editing is used and whether it *should* be used or not. These questions are essential for assessing whether the training is the "sustainable model for the democratization of this technology" that organizers described it to be.

A further access issue the AfPBA left unaddressed was whether and how participants would access resources with which to generate CRISPR products of value. While many CRISPR-Cas components are relatively inexpensive or even free—an attribute that has contributed greatly to the democratization narrative—genetic mutation is only one step in a long R&D pipeline required to make agronomically viable plants. For example, the delivery of CRISPR-Cas components into plants cells (also known as "transformation") is often overlooked by non-biotechnicians, yet is a crucial stage in the genome editing process, and one that may require significant technical capabilities and incur sizable costs. At the Innovative Genomics Institute (IGI), a multimillion-dollar Plant Genomics & Transformation Facility—staffed by PhD students, postdocs, research assistants, and directed by a former research scientist with DuPont Pioneer—is responsible for developing the transformation protocols for major crop species. When the lab opened in 2017, the director explained that the lab had many new "gadgets" to aid its DNA-free delivery: $40,000 for a fluorescence microscope, $600 for a small tube of gold powder, and $30,000 for the DNA particle gun that shoots the CRISPR-Cas components into plant tissues (Weinstein, 2017). In the basement of the facility, specialized growth chambers assist in rearing seedlings under precisely controlled conditions, another vital step in the lab-to-land pathway. Each of the IGI's wheat chambers costs at least $100,000—and the facility has several. Thus, regardless of whether CRISPR-Cas is affordable, and irrespective of its intellectual property (IP) status, access is simultaneously configured by the familiar array of capital and labor—facilities, equipment, technical expertise, trained staff, and funding—that have long spelled the difference between having a technology in hand and having the power to use it.

The AfPBA did what it could within these constraints. It brought together major organizations and professionals on the frontlines of genome editing work (including the IGI and large agribusiness firms like Bayer and Syngenta).

3. Licensors offer 2 types of licenses: exclusive and nonexclusive licenses. Exclusive licenses give the licensee the sole right to use the licensor's IP and prevent the licensor from granting those rights to anyone else. Nonexclusive licenses allow the licensor to grant rights to multiple licensees at the same time. In this case, it is highly unlikely that International Institute of Tropical Agriculture (IITA) would have received an exclusive license, as this would imply a corporation or university granting IITA sole rights to use its CRISPR-Cas technology. More likely is that IITA holds a nonexclusive license, but it is not able to grant sublicenses under this license's terms. In this scenario, AfPBA participants are able to use the licensed technology while at the training, but not after.

4. *Nature*'s coverage of the AfPBA described the licensing conundrum as such: "In the course, participants will use IITA's CRISPR-Cas9 license, but back home they will need to make their own arrangements. Groover says he plans to introduce course participants to some alternative CRISPR editors, some of which are being developed at his institution, for which licensing might be less contentious, but which the U.S. government has been slow to regulate" (Nordling, 2023, p. 166).

It coordinated funds and negotiated access to licensed technology. And it received high-profile coverage in *Nature Biotechnology* with an article aptly titled, "Putting CRISPR into African hands to *future-proof* crops" [our emphasis]. But even with this show of power, course organizers acknowledged that the training on its own would be insufficient to bring a genome-edited product to market and perhaps even to undertake subsequent research. The logistical and technical challenges noted here (regulations, licensing, equipment) were obfuscated by future-oriented narratives such as "making the impossible happen." Yet it is within such messy materialities that new technologies are shaped, used, and/or discarded.

Interrogating the future of genome editing

Though impressive in scope, the case of AfPBA showcases several gaps between the rhetoric and reality of genome editing, chiefly around the need for, and limited access to, licenses for high-value patented technologies. This is reflective, in part, of the complex CRISPR licensing landscape. The main holders of foundational patent rights (University of California [UC], Broad/Harvard/MIT, Vienna University, Vilnius University) have established a now-familiar pattern of licensing rights to downstream users. For commercial agricultural applications, the UC manages CRISPR-Cas licenses via its spinoff Caribou Biosciences and the agribusiness giant Corteva Agriscience. The Harvard/MIT/Broad group, in a joint agreement with DuPont Pioneer (now Corteva), has taken a somewhat different route, granting nonexclusive licenses to IP under their control for use in for-profit agricultural research and product development. Vilnius University in Lithuania, whose IP overlaps with that of UC, has also licensed its foundational IP to key agribusiness developers. In addition, Corteva, Bayer, and Syngenta/ChemChina now have many of their *own* CRISPR-Cas patents, with their own licensed methods and products, contributing to a byzantine and ever-expanding CRISPR IP landscape (Sherkow, 2018).

Despite the proliferation of contracts for commercial use, CRISPR-Cas9 technologies have long been provided free of charge to academic and nonprofit researchers. The UC offers free use of the CRISPR platforms and components it controls, while a joint agreement between the Broad Institute and DuPont Pioneer provided a framework for making foundational IP for CRISPR-Cas9 freely available to universities and nonprofit organizations for research (Cameron, 2017). In 2023, Syngenta announced *Shoots by Syngenta*, an initiative that allows academic institutions to license Syngenta's products for research. These free access for noncommercial use initiatives are a core aspect of the "democratization" discourse, especially as it pertains to research communities in the Global South (LaManna and Barrangou, 2018).

However, while noncommercial use licensing can expand the research landscape of genome editing, it can also set limitations on how research becomes commercialized. Consider, for instance, *Shoots by Syngenta*,[5] which offers access to 7 patented genome editing products through research licenses. The program aims to "accelerate innovation through collaboration in agriculture" (Syngenta, 2024b). If a licensee, such as a university-based researcher, wishes to commercialize a product developed through Syngenta's licensing, "improvements [will] remain the sole property of the licensee" (Syngenta, 2024a). That is, the researcher maintains ownership rights to their innovation. Syngenta, however, also retains the right to commercialize the "improvement" of the licensee: "a grant back clause is present in the license and entitles Syngenta and its affiliates to research, develop, and commercialize the improvements made by the licensee including the right to sublicense in its normal course of business" (Syngenta, 2024a). This arrangement provides Syngenta with relatively inexpensive access to expertise at the country level, which it can capitalize on through further research and commercialization. While this sort of agreement may benefit the licensee, ultimately it is Syngenta that sets the terms of collaboration.

The setup of *Shoots by Syngenta* represents an evolution from earlier eras of biotechnology. The initial life sciences boom of the turn of the 21st century was spurred on by narratives of a "revolutionary" technology, from personalized medicine (Rajan, 2006) to genetically modified (GM) crops for the poor (Glover, 2010). In the United States (US), the revolutionary future framing was adopted by scientists, industry, and venture capitalists alike (Rajan, 2006). While competition among biotechnologists might have spurred innovation, it was also deeply entangled within capitalist structures (Rajan, 2006). In its early years, the biotechnology industry was marked by constant mergers, acquisitions, and fierce patenting battles. Within the realm of plant science, a small number of companies emerged as front-runners in capturing the market, including Monsanto (now Bayer) and DuPont (now Corteva). This, however, sparked distrust from sectors of the public, who accused said companies of corporate concentration and the patenting of life (Schurman and Munro, 2010).

Importantly, biocapital (Rajan, 2006) continues to shape the nascent genome editing landscape. The example of the AfPBA—where some countries were targeted for their permissive (or expectedly permissive) regulatory regimes—is instructive here. Participants from countries with, or soon-to-be, "relaxed restrictions" were invited to participate in the training, while everywhere else was described in a *Nature Biotechnology* article as "less prepared for the new technology" (Nordling, 2023, p. 166). In this imaginary, the continent is envisioned as unprepared for the bounty that biotechnology will bring, with development and progress equated to relaxing regulations on the free flow of capital.

This is the backdrop upon which discourses of genome editing as "democratizing" and "collaborative" have emerged (Montenegro de Wit, 2020). Discourse here, whether about the present or the future, is used to cement a break with earlier biotechnology pasts (Rock et al., 2023b). In Japan, Yamaguchi (2020) argues the performance of optimistic expectations around genome editing has been successful in garnering support, building networks, and attracting resources. Similarly, Lindberg et al.

5. *Shoots by Syngenta* is run by the Syngenta Group, which is owned by ChemChina.

(2023) chart how both supporters and opponents of genome editing in the European Union utilize future expectations in attempts to sway public opinion and regulatory officials. Putting expectations to the test, Beumer and de Roij (2023) examine how a certain "promissory narrative"—that genome editing will be used to "improve" crops for smallholder farmers (Pixley et al., 2022, p. 364)—operates in practice. They analyze genome editing initiatives targeting smallholder farmers and find that (a) few smallholder projects are actively underway and (b) projects varied substantially in the quality and extent of smallholder participation. They conclude that, at least for now, narratives of genome editing "accelerating research [. . .] [for] farmers in the developing world," as proponents have claimed, is not the present reality (Beumer and de Roij, 2023, p. 6).

Important in the sociology of expectations and other STS orientations toward the future is the idea that the future is forever coming, which is at once appealing and strategic. If the future is always on the horizon, then it's always just around the corner but never actually here. The goalposts may get moved, but the future is imminent. Futures can therefore be both addictive and deceptive. Who doesn't want to imagine a different world? A better world? A more just world? However, if a new future is thus always coming, it also means that futures tend to obscure accountability (Rajan, 2006). As technology writer Rose Eveleth (2023) explains, because it is impossible to empirically groundtruth claims about the future today, those cheerleading future promises—policymakers, private firms, and more—achieve a Teflon-like resistance to scrutiny: "if you're one of these people, [you can] make claims and make promises and then not necessarily have to be held to them. Because you know, it's the future. Who can say? Who can know?" These questions point toward mechanisms of accountability: who keeps track of promises of the future, and who is held to account if the future doesn't resemble that which has been promised?

It is important to pay attention, then, to *histories of futurities*. In the context of biotechnology, the newest technology is typically contrasted with a slightly older technology, which is suddenly cast aside as flawed, error-prone, even obsolete. An iconic term used to describe CRISPR and to distinguish it from other processes is "precision." In their heyday, genetically modified organisms (GMOs) were similarly depicted as precise relative to mutation breeding. More recently, "prime editing" and "base editing" are being heralded as new precision instruments, while CRISPR-Cas9 is suddenly "prone to errors" (Ledford, 2019, p. 464 *quoted in* Heinemann et al., 2021, p. 9). Indeed, despite narratives espousing genome editing's revolutionary power, precision remains a challenge in practice (Pixley et al., 2022; Wang and Doudna, 2023). Moreover, certain traits, including abiotic stresses such as drought (Schnurr et al., 2022), and certain vegetable crops (Das et al., 2023), present persistent hurdles for breeders.

The temporality of the ever-receding future buries the past and present. It also sweeps aside potential limitations, such as imprecision and cost, as problems that can and *will* be dealt with later—alongside any potential lessons to be learned from previous technologies. This is at once appealing and problematic. The experience of GM crops in Africa is instructive here. GM crops have produced only modest adoption rates across Africa, due in part to poor crop performance (Luna and Dowd-Uribe, 2020), mixed reactions from farmers (Schnurr, 2019), institutional challenges (Dowd-Uribe, 2023), and varying technical resources of Africa-based scientists and companies (Adenle, 2014). The halting trajectory of this previous generation of breeding technology reminds us of the myriad variables that extend "beyond the genome" (Rock et al., 2023b). Such considerations tend to be excluded within the hype accompanying new breeding technologies but play a critical role in shaping real-world outcomes.

Making futures

The question of agricultural transformation has been a fixture of the 60 years since decolonization movements swept the African continent. Presently, the "new" Green Revolution for Africa model dominates donor and government initiatives across the continent. This project, ongoing since the 1980s, seeks to alter African agricultural landscapes, in part by spurring an "agricultural exit," moving the continent's smallholder farmers into off-farm employment, and combining smaller plots into larger land holdings (Rock, 2022). For some, this process is key to spark industrialization and economic transformation. For others, the merging of farmland means dispossession of land and livelihoods. Farmers, meanwhile, seldom work within a singularly defined approach (Nyantakyi-Frimpong and Bezner Kerr, 2015; Shilomboleni, 2018). Similarly, scientists on the continent utilize various modalities depending on the research project and resources available (Adenle, 2014; Rock, 2022).

Diverse agricultural practices abound. However, this diversity can become obscured within current genome editing discourse, which charts agricultural transformation as linear, production-based, and dependent on technological advancement. Indeed, obfuscation tends to be a function of promissory narratives. But conversations around genome editing need not be confined to discourses of pros/cons, access/inaccess, inclusions/exclusions, possibilities/impossibilities. Decolonial, feminist, and Indigenous STS scholarship locate these dualisms within a modern-colonial imaginary from which the future can be fruitfully unbound. These scholars call attention to speculation, reclamation, and refusals of this type of world-making and seek to decenter white settler and heteronormative concepts of life, death, reproduction, sustainability, and power (Hernández, 2019; Bisht, 2020). Rather than ask about *the* future, they suggest we should attend to multiple and diverse horizons, pasts, and presents (Terry et al., 2024).

Importantly, these futures can break from core epistemological assumptions of modernity, in which nature is something to be controlled through techniques like genome editing. Futures can instead be organized collectively, in relation to (more-than-human) life, and through active sites of political struggle. As the transnational peasant movement La Via Campesina wrote on its 25th anniversary, food sovereignty is a vision "for our collective future, and defines the principles around which we organize our daily living and co-exist with Mother Earth" (La Via Campesina, 2021). La Via Campesina, along with continental actors such as the Alliance for Food Sovereignty in Africa, call attention to more grounded approaches to agricultural systems, like agroecology, as a promising means for enhancing African farming systems. Yet these practical strategies get nowhere near the attention nor the funds relative to "groundbreaking" technologies like genome editing (IPES Food, 2020). Technological co-creation—like that surveyed in Beumer and de Roij (2023)—is possible but requires a reorientation of will, funds, and epistemological biases.

If, as the common genome editing narrative suggests, "democratization" of science is to be pursued, then doing so must center the diversity of scientific and agricultural practices and grapple with the politics of making futures. And if the scope of what futures could be like, could look like, could feel like, are rich and pluralistic, then the questions we ask about them can be as well: Who has a seat at the future-making table for food and agriculture? Who designed that table and offered invitations? Who is missing from that table, and what sort of future(s) are they working toward? How can alternative tables—and futures—be made?

The authors in this special feature first began discussing these questions at a 2-day workshop at Dalhousie University in 2022 in Halifax, Nova Scotia, Canada. The workshop, entitled "Genome Editing in Africa and Its Alternatives," invited participants from across the natural and social sciences to present papers on the past, present, and future of agricultural technologies, plant breeding, and agricultural systems on the African continent.[6] While the papers varied in geographic, temporal, and thematic scope, they were connected by an enduring, overarching theme: that the past is always present and is crucial to understanding prospective trajectories.

The 4 papers from Amanor (2024), Dowd-Uribe (2023), Rao (forthcoming), and Bezner Kerr and Wynberg (2024) examine legacies of plant breeding programs and biotechnologies in Ghana, Burkina Faso, Malawi, and South Africa. Collectively, these papers underscore regional complexities, diversities, and histories that are missing from homogenous narratives of "Africa" but are essential in orienting the present and future(s).

The article from Amanor analyzes how changing public policy and geopolitics have shaped agricultural development initiatives in Ghana. For example, Amanor chronicles how the implementation of structural adjustment in the 1980s—and the subsequent de-funding of public research efforts and institutions—led to donors prioritizing international research organizations such as the CGIAR. This created both a tension and interdependence between Ghanaian public research organizations and CGIAR; scientists within CGIAR had access to resources and would depend on public research organizations to run field trials. In turn, public researchers gained experience and were able to release new varieties. But as agricultural development trends shifted toward the private sector in the 21st century, rules of agribusiness—maximized productivity and capital gain—have come to dominate the sector, shifting both priorities and relationships within and across the CGIAR and public research organizations. In doing so, Amanor's paper serves as a stark reminder of the importance political economy plays in technology development and prompts important questions around whether (or not) and *how* plant breeding programs can include farmers' needs and priorities.

Similarly, the paper from Dowd-Uribe shows how two pillars of the Green Revolution—the prioritization of scale neutrality and technical expertise—guide genetic modification projects on the African continent. To do so, he follows the case of a public private partnership developing Bt cowpea in Burkina Faso. Despite project promises that Bt cowpea will benefit smallholder farmers, Dowd-Uribe shows how key decisions in the experimental process—including the use of a variety of cowpea preferred by commercial farmers and an absence of farmer participation in project development—serve to marginalize farmer preferences and priorities. The case of Bt cowpea in Burkina Faso provides ample food for thought for those planning to engage new technologies, like genome editing, for the benefit of smallholder farmers. Good intentions and innovative technology are not enough; planners must also interrogate their program design, epistemological foundations, and the diverse needs and priorities of heterogenous farming communities.

The paper from Rao is instructive here. Rao draws attention to the gendered components of food and agriculture through an examination of 3 biofortified crops: banana, quality protein maize, and sweet potato. She uncovers the gendered dynamics and implications of decisions taken during crop development, including trait and crop selection, as well as downstream activities like farm-level labor and eventual commercialization of crops. In doing so, Rao calls attention to the myriad considerations plant breeders must weigh when developing new crops, as well as the complex drivers of food insecurity and malnutrition. Ultimately, lessons from biofortified crop development and production point to the importance of structural, rather than simply technological, interventions.

Bezner Kerr and Wynberg look across the divergent yet overlapping histories and political ecologies of hybrid maize (Malawi) and GM maize (South Africa) to examine the intersection of agricultural modernization efforts and "colonialities of power, knowledge, and being" (Bezner Kerr and Wynberg, 2024, p. 2). To move beyond the latter, they draw from Quijano (2000) to develop a theoretical foundation for decolonizing food and agricultural systems. Their comparative analysis leads to a call for research systems that attend to diverse ways of knowing and are organized around the public good. In providing examples of what decolonial agricultural and food systems might look like, Bezner Kerr and Wynberg provide scaffolding for imagining and operationalizing plurifutures that

6. The workshop was part of a larger research initiative, the GEAP3 Network, an international research consortium that explored developments in genome editing, their implications for agriculture, across the United States, United Kingdom, and African continent. GEAP3 was funded by a grant from the Erasmus+ program of the European Union.

challenge the ideal of a singular mode of genome editing assumed to benefit African smallholders.

These 4 articles set the historical and political economic foundations for papers from Rock et al. (2023a) and Shilomboleni and Ismail (2023), which examine the emerging networks, projects, and worlds of genome editing in Africa to ask what role the new technology will, or will not, play in future plant breeding efforts.

Rock et al. explore the knowledge politics of genome editing through interviews with scientists, donors, and development experts engaged in genome editing work on the continent. They find that the technology is being rolled out unevenly. Scientists working within the CGIAR system, for instance, reported adequate access to materials and resources for using genome editing in their research. Meanwhile, scientists within public universities and research organizations shared difficulties in accessing grants and supplies for their work. While stakeholders across the board expressed excitement about the possibilities that genome editing offered, the unequal experiences of scientists within and outside the CGIAR system raise concerns around narratives of "accessibility" (cf. Pixley et al., 2022) and prompts the question: accessibility for whom?

Shilomboleni and Ismail examine if and how genome editing could assist countries pursuing larger goals of increasing national production and reducing rice imports. They review research where genome editing has been used to develop disease resistance, drought tolerance, and grain improvement in rice. While these advancements are promising, the authors caution that technical constraints (such as unintended edits) and social constraints (such as public acceptance and IP rights) remain. Given these realities and given that crop genome editing is still its relative infancy, Shilomboleni and Ismail suggest that scientists, policymakers, and donors adopt "responsible research and innovation" principles in their genome editing programs. This might include embracing uncertainty, engaging in constant reflexivity, and including "diverse stakeholders at early stage of innovation design *and* on a continuous basis" (Shilomboleni and Ismail, 2023, p. 8; our emphasis).

Taken as a whole, these papers shine a light on crucial factors that shape technology development, agricultural practice, and the politics of knowing. They also demonstrate the inextricable importance of place, and the persistent ways the past continues to shape our present and future. As much as the dominant discourse around genome editing wishes to break from the GMO past, we might do well to heed ways of knowing that foreground the past(s) to inform the present (Asare, 2023), and that attend to multiple, diverse futures (Terry et al., 2024). After all, every seed is a thread of social relations linking human histories on this planet to the earth on which our collective futures depend.

Data accessibility statement
Data sharing is not applicable as no new data were collected for this research.

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Competing interests
The authors have no competing interests to declare.

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