

RESEARCH ARTICLE

Democratizing CRISPR? Stories, practices, and politics of science and governance on the agricultural gene editing frontier

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Many trends in agricultural biotechnology have extended fluidly from the first era of genetic modification using recombinant DNA techniques to the era of gene editing. But the high-profile, explicit, and assertive discourse of democratization with gene editing — especially CRISPR-Cas9 — is something new. In this paper, I draw on semi-structured interviews with gene editors, policy analysts, and communications experts as well as with critical academic and civil society experts. I use Science and Technology Studies and political ecology lenses to unpack democratization in three main parts. First is democratizing discourses: On what grounds is CRISPR said to be democratic? Who is saying so? How do dissident communities respond to these narratives? Second is agricultural applications, with a focus on the Innovative Genomics Institute's work in developing gene-edited food crops, including a case of saveable clonal hybrid rice. Third is governance, where I contrast US Department of Agriculture regulations and the CRISPRcon conference as "closed" and "invited" spaces, respectively, for democratic participation. Next, I argue that "created spaces," in which power is held by typically delegitimized actors and ideas, offer an opening for working out democracy on the terrain of biotechnology. I conclude with a set of principles and practices for CRISPR governance based on the idea that democratization of biotechnology requires epistemic justice. By gathering multiple, partial knowledges together, we move beyond narrow risk-benefit framings to better evaluate not just what CRISPR is and does, but what democracy means and whom it serves.

Keywords: Gene editing; CRISPR-Cas9; Food systems; Intellectual property; Democratization; Agroecology

I. Introduction

It was February 2019, and in front of a packed auditorium at UC Berkeley's International House, Jennifer Doudna reflected on the impact of CRISPR's speed and simplicity: "It became a democratizing tool that allowed labs to do experiments that in the past had been prohibitive for various reasons, whether due to expense or just technical difficulty." Similarly, Rodolphe Barrangou, editor-in-chief of *The CRISPR Journal*, told *National Geographic* in 2018, "CRISPR has been democratized. With 100,000 labs and 10 people per lab, we now may have over a million geneticists working with this technology" (Niiler, 2018).

And it's not just CRISPR pioneers. Increasingly many scientists, journalists, and business entrepreneurs are invoking the discourse of democratization. Since its discovery in bacteria by Barrangou in 2007 and development into a genome editing tool by Doudna and others in 2012, CRISPR-Cas9 has been heralded by the research community as "breakthrough" technology (*Science* 2012, 2013, 2015).¹ It has suffused fields from basic biological

research to human therapeutics, wildlife conservation, military/defense, and agriculture. It has been shown to work in a tremendous variety of organisms from the simplest of soil microbes to complex organisms including insects, plants, fish, animals, and people. While early research focused on proof of principle in a few cultivated species such as wheat (Upadhyay et al., 2013; Wang et al., 2014), rice (Shan et al., 2013; Zhou et al., 2014), and tomatoes (Brooks et al., 2014), in the past five years, science has turned to agronomically relevant traits: boosting resistance to viral and bacterial diseases, enhancing drought resilience, eliminating natural toxins in root crops, creating hybrids through clonal seeds, and accelerating the domestication of wild plants (Borrelli et al., 2018; Gomez, 2019; Khanday et al., 2018; Lemmon et al., 2018).

CRISPR has also entered into debates about "feeding the world." Contrasted to classical plant breeding on one hand and conventional GM technology on the other, gene editing figures prominently in the World Economic Forum's "Innovation with a Purpose" Initiative (WEF, 2018), the National Academy of Science's "Breakthroughs to Advance Food & Agriculture Research by 2030," (NASEM, 2019), and the World Resource Institute's report,

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“Creating a Sustainable Future” (Searchinger et al., 2019). In these fora, gene editing supports a larger paradigm of Sustainable Intensification, which proposes to increase yields while reducing the energy-dependency and biodiversity costs of industrial farming (Royal Society, 2009; Pretty et al., 2018). As applied to less economically advantaged countries, and African countries especially, gene editing advances a “Second Green Revolution,” where intensification is seen as vital not only for food production but for modernization and economic development (Conway, 1998; Ickowitz et al., 2019). A CRISPR-enabled crop revolution thus promises to reduce pesticide inputs globally, provide health benefits to consumers and agronomic advantages to farmers, and pave a pathway out of poverty for poor countries around the world. Although many claims are only speculative at this point – CRISPR-edited organisms have yet to be commercialized on a wide scale – revised US regulatory policies, intellectual property developments, and updated trade rules attest to structural changes making way for CRISPR (Contreras and Sherkow, 2017; USDA/APHIS, 2019; White House, 2019).

Clearly, with CRISPR, as with any breakthrough innovation, comes a spectrum of possibilities. Will CRISPR be a tool that reinforces existing sociotechnical lock-ins characteristic of the industrial agri-food system (IPES-Food, 2016)? Could it provide an opportunity to counter such trends by democratizing science, diversifying crop development, and re-distributing the loci of ownership and control? Who owns this technology, who has access to it, and who is making decisions about its development and use?

In this paper, I focus on democratization as a prominent discourse surrounding CRISPR. While GMO governance underwent an “ethical turn” in the early twenty-first century, granting public concerns more of a voice in expert-led policy, explicit pleas by scientists and industry for biotech democracy did not figure prominently into first-generation GMO conversations. One reason was the material reality of biotech production: highly centralized, concentrated, and capitalized centers of R&D made it hard to credibly argue that GMOs were “by the people” or “for the people” (Schurman and Munro, 2010). Another reason was serious compromise in the ethical turn, in which a strong expert/lay divide continued to cast expert knowledge as grounded in reality while lay knowledge and attitudes were seen as “politically real but intellectually unreal” (Wynne, 2001). A third reason was civil society resistance. Peasant, food justice, and food sovereignty movements were never convinced by gestures to participation and have almost universally rejected genetic engineering as embedded in a corporate food regime whose values contravene justice and democracy (Pechlaner and Otero, 2008; LVC, 2011; USFSA, 2014).

Against this backdrop of a generation of GMOs, which according to many social scientists and civil society actors was so *un*-democratic in practice, it is remarkable to see CRISPR declaratively cast in democratizing terms. Also remarkable is the implicit turf war this claim produces. For while claims to speed, precision, efficiency, and abundant yield are all features that biotech critics will challenge on the necessity of those features, democracy is different – it

is a tenet considered dear to biotech’s staunchest critics. For food sovereignty, seed sovereignty, and agroecology movements, deepening what democracy means, on whose behalf it works, and the extent and quality of community participation in governance animates a growing area of theory and practice (Carlson and Chappell, 2015; Dumont et al., 2016; Anderson et al., 2018).

With rivaling paradigms invoking democracy both to defend and to reject genetic engineering, the time is right to ask: What does it mean to democratize CRISPR? Who is making this claim and how? Under what conditions might CRISPR *become* democratic, if it is not democratic now? In asking these questions, I wanted to move out from beneath the staggering weight of *democracy* as a concept. What follows is not a treatise on political theory or an exploration of democracy’s different assumptions, rationales, and limits. What I attempt to do is understand what “democratizing CRISPR” means to those who invoke it. I also look at how this meaning morphs as CRISPR-Cas9 travels from being a basic tool/technology into being applied to the making of gene-edited crops and foods. Does a democratized tool produce a democratized seed? If, at its most fundamental, democracy is “rule by the people,” it is important to ask how the politics of participation are shaping up. Who is included, or not included, in decisions about CRISPR science, policy, and governance, and to what effect?

The focus of my inquiry was the Innovative Genomics Institute (IGI), an epicenter of gene-editing research, established in 2015 in partnership between the University of California, Berkeley and the University of California, San Francisco. I conducted semi-structured interviews with eight scientists, research and policy staff, and communications experts affiliated with the IGI, alongside four non-IGI CRISPR researchers with expertise in molecular biology, industrial applications, and IP (see Text S2). In parallel, I sought contrasting perspectives with interviews from ten sustainable food systems scientists (in both natural science and social science disciplines), civil society activists, and researchers in organizations known for work in areas of food sovereignty, agroecology, indigenous rights, and genetic technologies (see Text S3).² Participant observation at the IGI, two CRISPRcon conferences, and three other CRISPR symposia and workshops sponsored in part by the IGI complemented this work; I was able to interview conference organizers and participate in dozens of conversations that while “off the record” nonetheless deepened my understanding of salient issues. As discourse is central to my analysis, I also reviewed multiple types of CRISPR literature, including a survey of “democratization” in peer-reviewed, popular, and industry writings over the past seven years of CRISPR-Cas9 development.

In what follows, I begin with a brief overview of democracy and science, primarily from the vantage point of science and technology studies (STS). I then turn to democratization processes in three main parts. First is democratizing discourses. On what grounds is CRISPR said to be democratic? Who is saying so? How do “dissident” scientists and movement actors respond to these narratives? Second is agricultural applications, with a focus on

the IGI's work in developing gene-edited food crops, and a case study of saveable clonal hybrid rice. Third is governance, where I contrast US Department of Agriculture regulations and the CRISPRcon conference as "closed" and "invited" spaces, respectively, for democratic participation. I conclude with a sketch of "created" spaces that gather multiple, partial knowledges together to evaluate social and ecological concerns beyond the narrow scope of risk/benefit framings. In such spaces, typically disempowered and delegitimized voices can shape not just what CRISPR is and does, but what democracy means and whom it serves.

II. Democracy & science: a view from the looking glass world

The entanglements of science and democracy have provided a rich terrain for STS analysis since the 1970s, and even more so in the 1990s and 2000s as concepts of "knowledge politics" and "co-production" provided the field with new purchase on old material and epistemic questions.

A foundational idea driving this inquiry has been passed down from Enlightenment thought: *science and technology is central to the making and doing of democracy*. Embraced by thinkers from Bacon and Descartes to Jefferson and Voltaire, what Sarewitz (2000) dubs the "Enlightenment program" for science put empiricism, rational thought, and control over nature at the roots of liberal democracy. Essential to this program is the assumption that the benefits of science flow automatically to society, such that a progressive increase in the reservoir of fundamental knowledge results spontaneously in greater social good. Free operation of the market economy, moreover, can mediate this flow, brokering an unobstructed pipeline of innovations to benefit humanity. Reframed in its modern guise by Vannevar Bush in his famous report "Science, the Endless Frontier" (1945), the Enlightenment program was implemented in its most successful form by Cold War organization of US science and is internalized, Sarewitz suggests, "at every level of the diverse and complex modern research enterprise, and throughout industrialized society as a whole" (Sarewitz 2000, 90).

Today synthetic biology, artificial intelligence, and armies of drones and driverless cars attest to a persistent faith in the power of precision and control. Accelerated by the synergistic rises of ever bigger Big Data, smaller molecular resolution, and cheaper information technology, many trends in science circa 2020 remain faithful to reductionism as the sure path to comprehending nature. In this context, the "God trick," to echo Haraway (1988), has expanded its panoptic *trompe l'oeil*, in which universality provides the justification to make rational knowledge claims. If mass surveillance, the end of effective antibiotics, and runaway climate change evoke existential anxieties about technoscience systems that produce crises as readily as they solve them, the Enlightenment rationale has an answer for that too: more science. In spite of little evidence that the overwhelming amount of data available today is translating directly into better (more just, equitable, sustainable) decisions, "sound science" provides us

with a surrogate for political conversations. The demand for "more information" replaces democratic decision-making, while the promise of democratized science was, and remains, freedom from uncertainty.

Several ideas grow from this epistemic foundation, which STS and related fields have shed light on over the years.

First is that uncertainty is not so much a problem to "fix" as it is *a fixture of both nature and the scientific process itself*. Research spanning resilience theory to epigenetics to agroecology reveals a central paradox: while the scale of control afforded by science advances, so does the domain of uncertainty and potential risk (Shattuck 2019, Stone 2014, Murphy 2006). Feminist perspectives have further destabilized certitude, arguing for politics and epistemologies of location, positioning, and situating, where partiality and not universality is the condition of being heard to make rational knowledge claims (Haraway, 1988; Harding 1991). Enlightenment rationale, crystallized in the Royal Society's motto *nullis in verba* ("nothing (proved) by words") sums up skepticism towards what is merely written or spoken, towards any theories that could not be demonstrated repeatedly in front of an educated audience in quiet and orderly space (Shapin and Schaffer, 1985). Yet decades of scholarship within and beyond the academy have shown not only the surprising, stochastic, discontinuous nature of social-ecological change (Holling, 1973), but also how logics of predictability and control spread across Europe and her colonies to systematically marginalize other forms of producing knowledge (Mitchell, 2002; Dussel, 2013; Klein, 2014).

A second idea is that while science is widely regarded as foundational to democratic practice, *invoking science can in turn lend authority and legitimacy to democracy*. The coproduction of science and democracy can be seen in concepts like the "scientific method," which is seen as non-discriminatory: anyone can ask questions and test knowledge; anyone can observe the natural world and develop hypotheses. Generating more and better scientific knowledge is therefore a democratizing force, helping people to become better citizens who reason more accurately and intelligently. At a larger scale, science and technology can support modern democratic states to accomplish their goals, like building armies, controlling pollution, or providing healthcare. By depending on scientists and technical experts to inform policy processes, governments gain the authority of science – understood to be apolitical, unbiased, and universally true. STS works to deconstruct these assumptions, pointing to the inadequacy of models that "employ wholly different explanatory resources to explain the production of scientific knowledge (or uncertainty) on the one hand, and the production of political order (including policy choices) on the other" (Jasanoff and Wynne, 1998, 16). From this perspective, we need a more interactive accounting, in which natural knowledge and political order are coproduced "through a common social project that shores up the legitimacy of each" (ibid).

A third idea is that *science and technology are intrinsically equalizing*. The democratization of a technology by dissemination to scientists and engineers in less advanced

countries frequently is understood as the march of modernity: a global unleashing of societal progress. Whether aided by private philanthropy or government-assisted “technology transfer,” expanding S&T globally hedges against illiberal governments, unleashes entrepreneurship, and stimulates ideas, opportunities, productivity, and economic growth. The issue, as STS scholars and others observe, is that while science and technology have inarguably transformed the structure of society over the past several hundred years (usually without the consent of the governed), this transformation process seems to have exacerbated inequitable distribution of wealth, rather than smoothed it (Sarewitz, 2000). At the very least, accelerated industrial and post-industrial growth has given us something impossible to ignore: a considerable increase in concentration of wealth in the world (with many of the wealthiest owning technology companies). This concentration contradicts a core tenet of the Enlightenment program – that new knowledge should be cosmopolitan in its benefits – but provides greater insight into the appropriation of resources and knowledge that have accompanied the globalization of science.

A final key idea for our purposes is that the making, using, and disseminating of science and technology can in theory be democratic. In practice, however, *STS scholars see S&T as lacking in democracy in a fundamental sense*. Some reasons include:

- The *demos* of science – Scientists and technologists tend to be drawn from a narrow subset of society, in terms of race, class, worldview, and geography. This insularity affects what they research and how (Kleinman, 2000).
- Institutional history – Education and training in science is often limited to specific institutions, such as US land grant schools, in the case of agriculture. Access to S&T knowledge is therefore mediated by the racialized and gendered histories of these spaces (Williams and Williamson, 1988), as well as by industry influences over research that have not always served the public interest (Buttel and Busch, 1988; Goldstein et al., 2019).
- Social priorities – Methods of science and technology lack connection to societal priorities and needs. Although strong countercurrents exist, research seldom begins with the question: “What science is socially necessary?” Mainstream logic of S&T holds that basic science flows linearly towards social applications, leaving few pathways for society to provide feedback or intervene upstream.
- The *lay/expert divide* – Sharp lines exist between “lay publics” and “expert scientists,” as well as between the domains of “technical and “non-technical” knowledge. If lay people are allowed to participate in matters concerning science, they are often confined to non-technical issues (“values” or “ethics”) while experts handle the technical issues (“science”) – reinforcing the separation of those spheres. As Wynne (2001, 445) notes, this division rests on “deeply cultural presumptions of a categorical divide between

factual, objective and real knowledge on the one hand, and cognitively empty emotion or values on the other; and that whilst science looks after the former, lay publics are only capable of taking sentimental, emotional and intellectually vacuous positions.”

- Ethics and risk – Institutionalized expert and policy discourses tend to split “risk” from “ethics” (Levidow and Carr, 1997), obscuring implicit ethical choices embodied in scientific regulatory processes. Biotechnology in particular, STS scholarship suggests, has provided “a wider audience for public debate, while setting the terms for expert regulatory procedures, generally within a neoliberal “risk–benefit” framework” (Levidow, 1998). This dichotomy excludes non-scientists from participating in risk assessment and treats risk as unmoored from ethical assumptions. A wider set of societal concerns – including corporate control of food systems, loss of consumer choice, disruption to smallholders’ agroecosystems and sovereignties – are simply not captured by the formal and technical language of safety and risk (Macnaghten and Habets, in review).
- Political economy of science – Science and technology produce and reflect the political economies in which they are embedded. Biotechnologies designed to enable appropriation and accumulation (eg., Goodman, Sorj, and Wilkinson, 1987) cannot help but produce frictions between science and democracy. In this sense, the undemocracy of S&T under capitalism may be viewed less as aberration than as a requirement for the production and reproduction of capital.
- Multiple ontologies and epistemologies – Knowledge itself is limited to dominant scientific and technical forms, excluding or marginalizing other types of knowledge and worldviews that citizens might have, hold, or rely upon. Indigenous knowledge is a particularly strong example of ontological systems that can complement Western science, but often struggle to be legitimized against it (Agrawal, 1995; Bala and Joseph, 2007; Vandermeer and Perfecto, 2013; Isaac et al., 2018).

III. Discourses of democratization

Against this backdrop, in which neither science in general nor biotechnology specifically are on sure footing with democracy, it helps to begin on gene editors’ terms. What are the arguments we are seeing for why CRISPR is a “democratizing” technology? On what grounds is CRISPR democratic? Who is saying so?

My review of popular science publications, general interest news, peer-reviewed literature, and trade industry media reveals arguments falling into four main categories:

- (1) cheap, meaning affordable to those who might not otherwise be able to afford it. The *economic barriers* to entry are lower.
- (2) user-friendly, meaning accessible to those without expert knowledge or substantial experience. The *knowledge barriers* are lower.

- (3) “free” from regulation. This means fewer pesky regulations for companies to contend with. The *regulatory (and thus cost) barriers* are lower, giving small companies greater ability to compete.
- (4) “free” from IP. This connects to open science, meaning *property barriers* are lower, at least for non-profit research use.

Low cost is by far the most commonly invoked argument. For example, on the Baylor College of Medicine Blog, Christopher Scott, M.D. (2018), writes:

First- and second-generation gene editing technologies³ rely on cumbersome and expensive protein engineering approaches. CRISPR, by contrast, is way cheaper – 100 times cheaper, in some cases... Take this together and you have what science policy scholars call a ‘democratizing technology.’”

Similarly, James Haber, a molecular biologist at Brandeis University told *Nature News* (Ledford, 2015) that in contrast to older gene editing tools, which cost \$5,000 or more to order, CRISPR works differently:

Researchers often need to order only the RNA fragment; the other components can be bought off the shelf. Total cost: as little as \$30. “That effectively democratized the technology so that everyone is using it,” says Haber. “It’s a huge revolution.”

After cheapness, less specialized knowledge is the second most frequently cited argument for democratization. For instance, Dr. Jon Chesnut, a synthetic biologist at Thermo Fisher Scientific, suggests:

The aim of many of the new tools is to allow scientists to carry out research such as creating mutations in cell lines, even if they aren’t dedicated genome engineers (Chesnut, 2017).

Likewise, Samuel Sternberg, M.D., on the Columbia University of Medicine blog argues:

This technology has democratized genome editing so that it’s no longer something that only highly experienced individuals can implement (Sternberg, 2019).

Lower knowledge barriers to entry plus lower economic barriers to entry results in “DIY.” The MIT Technology Review’s Antonio Regalado (2015) offers a classic example:

This one should keep you up at night. CRISPR is so accessible—you can order the components online for \$60—that it is putting the power of genetic engineering into the hands of many more scientists. But the next wave of users could be at-home hobbyists. This year, developers of a do-it-yourself genetic engineering kit began offering it for \$700, less than the price of some computers...Watch out, world.

As Regalado’s comments indicate, already in 2015, people were debating the pros and cons of expanding CRISPR access — “Watch out world” harbinger of uncontrolled “dangerous” experiments. On the other hand, scientists like Doudna continue to defend such access as an equalizing force. Speaking to a live audience at Stanford in 2019, she said part of what makes the CRISPR “democratizing” is that “You don’t have to have money, or a lot of connections; you don’t have to know who knows somebody ... to get a hold of [the technology]” (Shao and Pershad, 2019).

This anti-elite argument can be seen, too, in a third category of claims I found, where democratization is pegged to regulatory oversight. While expensive regulations on GM technology in the US have favored a few large companies, according to *The Scientist*, “products generated by gene-editing techniques such as CRISPR have historically not been subject to the same rules, meaning that a larger number of smaller companies can afford to get into the sector” (Taylor, 2019). Arguments in favor of “the little guy” are not just the purview of small company CEOs. Prominent science journalists also connect low cost and usability to a democratization ethos. Writing in *Scientific American*, Stephen Hall (2016) suggests:

“The ease and relative thrift of CRISPR have also allowed academic labs and small biotechs back into a game that has historically been monopolized by big agribusinesses. Only deep-pocketed companies could afford to run the costly regulatory gauntlet in the beginning...”

Freedom from regulations, in other words, is proposed as democratic, unlocking the potential for the underdogs to get ahead. The logic here overlaps considerably with the fourth and final type of argument I traced: freedom from intellectual property.

Here an article in *The CRISPR Journal* by Caroline LaManna and Rodolphe Barrangou (2018) captures the idea.

Enter Addgene. What started as a nonprofit organization aimed at disseminating valuable biological material between academics has rapidly turned into the key enabler of the democratization of CRISPR technologies.

Addgene is a non-profit global repository that gives researchers access to CRISPR plasmids — small circular pieces of DNA — at little cost beyond shipping and handling. Leading academic institutions that control CRISPR intellectual property, including the Broad Institute and MIT as well as UC Berkeley, offer free use of the technologies they own for non-commercial purposes through Addgene (Egelie et al., 2016).⁴ As of May 2018, Addgene has shipped nearly 1 million plasmids and 6,300 ready-to-use viral vectors to scientists at more than 6,200 institutions in almost 100 countries. When I spoke with Barrangou in June 2019, he indicated that the numbers were still accelerating, evoking a broader social trend. “CRISPR is no longer an exclusive technology but rather

universal – internationally, culturally, and socially” (pers. comm.; see also Barrangou, 2018).

My analysis of these narratives (**Figure 1**) suggest that they speak primarily to a *demos* of other scientists, rather than to citizens or the public more generally. The populist DIY rhetoric, moreover, obscures a reductive rendering of access and what Levidow (1998) has called a “technologizing of democracy” that is further elaborated in the following critiques from dissident scientist and movement actors.

A first concern is lack of authentic *epistemic access*. When it comes to CRISPR, Miguel Altieri, emeritus professor of agroecology at UC Berkeley, told me, “social movements will reject any technology to which they do not have access.” Open databases may provide physical access to guide RNA sequences, but in addition to assuming that farmers have access to computers and rural broadband, it assumes that genomics is a language that farmers can speak. This points to an important distinction between access to information and legibility, or access to meaning.

Legibility, in turn, rests on accumulated access to education and training, funding to make advanced studies possible, and a scientific community to support sustained learning. Thus, claims to lowered barriers to expertise with CRISPR are not without merit: A “non-expert” physician at UCSF can now generate knock-out mice to study disease, something unheard of a decade ago. But the barriers do not come down fully, or evenly: geneticists, physicians, and even urban DIY users benefit from privilege that does not extend easily, if at all, to smallholder farmers or rural communities, especially though not only in the global South.

Nonprofits like Addgene have gone some way to leveling this field by providing open access educational materials about CRISPR for anyone to read, download, use,

and share. Such systems generally work well to provide researchers outside of elite institutional networks with access to technical information. They work less well to provide an education that extends beyond the instrumental – to include social and environmental relationships, political-economy contexts, and ethical criteria that always shape the technical, whether explicitly recognized or not. In this way, the education offered in these fora does less to bridge, challenge, or close the access gap Altieri referred to as much as it reinforces a technoscientific approach to problem-solving across a global online population of self-selecting learners.

A second critical concern is that of *access to material and knowledge of practical utility*. For the majority of farmers, the real question posed by “access to CRISPR” is not actually access to the tools of CRISPR technology. It is access to its products – gene-edited crops and seeds, whose use rights are determined by intellectual property. It is also the question of *losing* access to traditional cultivars that might be displaced with expanded markets in new biotech crops, or mined as genetic resources for breeding gene-edited varieties. Here, claims about CRISPR’s freedom from IP are not untrue. Invoking “democratic CRISPR licensing” arrangements, the major university and corporate IP holders like DowDuPont (now Corteva Agriscience)⁵ are granting free licenses to scientists and non-profit organizations (Cameron, 2017). This is the IP freedom that enables Addgene to function as a plasmid clearinghouse. This is also the freedom that would give any farmer, like any scientist, the legal ability to use CRISPR-Cas9 for basic non-commercial research. But the freedom does not cover commercial licensing – and therefore the unit most relevant to farmers. Even while a heated university battle over foundational rights in eukaryotes remains unresolved, a 2016 review of the IP landscape by Egelie et



Figure 1: Discourses of democratizing CRISPR. A sample of clippings from popular media, trade industry blogs, medical research news, and peer review literature provides a snapshot of the various contexts within which the democratization of biotechnology – and biotechnology’s ability to democratize science and society – is expressed. DOI: <https://doi.org/10.1525/elementa.405.f1>

al. (2016, 1028) found that “larger industry players, with Dow and DuPont at the forefront, already appear to be more in control of the technology’s agricultural and food applications.” ChemChina’s acquisition of Syngenta in 2017 is thought to be funneling IP from China’s burgeoning academic CRISPR sector into Syngenta (Cohen, 2019).

Such trends offer few signs that companies will change their practices of patenting genetically engineered seeds. Likewise with the R&D pipeline: DuPont Pioneer’s waxy corn, one of the first gene-edited crops to be greenlighted by the USDA, is expected to be released into US markets sometime in 2020 bearing standard utility patent restrictions for one-time use. According to Andy Jones of Corteva Agriscience, such patenting will be “pretty much standard practice” (Bomgardner, 2017, Jones, pers. comm.). For farmers, access to seeds – the basic means of production – is the more appropriate level of analysis on which to focus the democratization question, and one explored in further depth below. To what extent will CRISPR’d seeds be free(d)?

A third, related, concern is *uneven access to infrastructure/resources*. Assume for a moment that the epistemic access barriers did not exist. We might imagine a team of trained plant biologists in Malawi who want to use CRISPR for small scale locally adapted breeding. Even these experts will need access to physical infrastructure, technical support, information systems, financing, and knowledge networks to achieve biotechnology products of significance. As with Green Revolution innovations, although the tools might be scale neutral (available to small and large holder alike), access to resources with which to make those tools functional is not.

Many CRISPR scientists do not disagree. When I spoke with Barrangou, he first suggested that online CRISPR kits prove the universality of access. “Any average civilian on the street can get their hands on the kit,” he said. “If you have the appetite for it, you can do it in the garage.” Yet such metaphors do not square easily with multi-million-dollar investments in labs and other infrastructure going to support a technology that is supposedly garage-friendly and dirt cheap. Barrangou helped reconcile this divergence with a more nuanced accounting of “access.” What Addgene provides through its plasmid repository and educational materials, he told me, is more akin to a basic recipe and ingredients – these are the essential tools to cook. “But to make a Michelin-star restaurant is not trivial whatsoever,” he said. “For that you need an *army*: of experts, equipment, genomes, screening, transformation, greenhouses, among others.”

A fourth point that sustainability scientists posed was the flipside of the access problem. What if CRISPR *were* to become more widely accessible, overcoming epistemic and resource boundaries? On this topic, Jack Heinemann, director of the Centre for Integrated Research in Biosafety at the University of Canterbury in New Zealand, underlined the difference between democratization and decentralization. As an example, he told me, let’s take guns. “If I make available all the tools to print a 3D gun, I’ve decentralized gun manufacturing and placed the social burden of decentralized gun manufacturing back on society.”

Exactly this situation arose in 2018 when plans to produce plastic guns on 3D printers in the US were nearly released online without any deliberative process among not only the people who wanted DIY weapons but among those who stood to be affected by them.

Applied to gene editing, we now have a situation where the technology is being touted as democratic partly because it is more affordable and easier to use. For Heinemann, in the absence of socially agreed-upon regulation and governance, we are effectively absolving government and industry from responsibility and devolving risk management to the local level. Or as he put it: “The democratization meme is really a socialization of risk meme.” Of course, risk to whom and what counts as risky are a set of questions with a contested political and social history (Beck, 1992; Carolan, 2008; Pechlaner and Otero, 2008).

Doudna has acknowledged this risk component more vocally in human germline editing⁶ than in agriculture. At the Stanford forum, in response to a question about the possibility of rogue states like North Korea obtaining and using the technology to create genetically edited babies, Doudna emphasized the importance of working with regulatory agencies in an international effort to create regulations and control for dangers (Shao and Pershad, 2019). Barrangou, too, indicated the importance of controlling rogue actors, though he suggested that regulations will not stop social outliers with ill intentions. “CRISPR is going to save lives and cure disease,” he told me, “We can’t say we aren’t going to use it because some idiot may weaponize it.” “Guns can be used for good or bad,” Barrangou asserted. “Twitter can be used for good or bad.”

The neutrality of technology argument, however, is not one that rests easily with scholars of science studies. “All tools have visions of intended use embedded into them,” said Adam Calo, a researcher at the James Hutton Institute who has studied the role of technologies like participatory mapping in affirming farmers’ agency and expertise. “These visions are both explicit as well as implicit. They may even be invisible to the designer, forged by their upbringing, worldview, and politics.” The “neutral tool” argument, Calo believes, obscures these assumptions of intended use. It is similar to the “guns don’t kill people, people do” claim, he offered. “Sure, I could use an assault weapon to prop up my tent. Does this benign use justify the legal protection of the weapon, of its continued production, of its widespread availability?”

These critiques of knowledge, seed, and resource access begin to pull at the edges of the affordable, easy, open-to-all discourse. But several scientists and activists had difficulty even responding to democratization in terms of the narratives offered. As Dr. Tom Wakeford – who has 25 years of experience working on participatory technology assessments internationally told me – “Democratization to me doesn’t have that meaning at all, so I am struggling with that as a framing of democratization. For me, to democratize means people have sovereignty over something, which means the right not to do it at all.”

Similarly, Devon Peña, a professor at the University of Washington and president of a non-profit that protects

“water democracy” in New Mexico and Colorado, found the terms of debate deeply insufficient. “In what way is the ability to order CRISPR online democratic?” he asked me. “Democracy requires accountability,” he said. “It requires consensus. It requires respect for local, place-based knowledge and institutions.” For Peña and others who represent and collaborate with indigenous communities, the divide between formal and informal seed systems is one that popular democratization narratives have a hard time traversing — even if CRISPR materials do not. Genes will inevitably flow from gene-edited crops to indigenous crops. The structure of food economies will shift, putting pressure on informal food systems to formalize and on smallholders to scale up. How can CRISPR, be democratic, they asked me, without acknowledging the rights of peasants and indigenous peoples around the world not to have their own seed systems, livelihoods, and identities destabilized without their consent?

Dr. Marcia Ishii-Eiteman of Pesticide Action Network North America suggested that CRISPR democratization must go beyond technical education and global access to cheap, user-friendly tools. Technology democracy, she said, is at its base a question of the people who will be directly and indirectly affected by it. Ishii-Eiteman emphasized that democratic approaches must begin with directly impacted communities — those who will be growing and eating and making a livelihood by these crops must have a central role in developing the technology. These communities should participate in identifying the basic research questions to be asked: “What problem can CRISPR solve?” “What problem is better solved by something else?”

Considering these discourses of CRISPR democratization shows key divergences between invokers of this concept and those who question or reject it. Providing access to a technology via significantly lower monetary, knowledge, regulatory, and property barriers is seen by some as a democratizing force. But others question who comprises the “demos” for whom such tools are legible, resource-enabled, and effectively available to non-scientists. For some, pushing for more universality is the answer, lending weight to the growing DIY movement of lay users. For others, ready access to technologies seen as risky, untested, or unnecessary, is itself deeply undemocratic, especially if disruptive to ecologies and communities where consent has not been sought or granted. While the who of democratization is contested, the “what” also contains fault lines. Despite the opening up of CRISPR IP for non-commercial research, CRISPR’s commercial development remains tightly bound up in patents and licensing agreements — a landscape already showing strong signs of agroindustry dominance. Democratization of the scientific process, that is, may not translate into democratization of gene-edited products, or the “what” that farmers care about.

Appraisals of the technology have also revealed different ontological and epistemological starting points. For disseminators of democratizing stories, technology is future-oriented, with tools like CRISPR propelling society onwards towards a better, more productive, more efficient future. For critics of this perspective, technology does not necessarily propel society forward, nor does it develop

linearly. Rather, technology follows historically contingent pathways, reflects the value systems of its makers, and as such, may also revive older forms of innovation. To paraphrase Aymara feminist scholar Silvia Rivera Cusicanqui, technology holds social promise when embedded in an ontology of renewal: it becomes a means to connect past, present, and future in a commitment to remaking the world (Cusicanqui, 2010). The question for CRISPR, then, is whether it can go beyond offering a more democratic technology for scientists and encourage its proponents to answer calls to democratization from other modes of thought.

To continue exploring these and other questions, we now turn to the University of California, where CRISPR tools meets agricultural applications. Moving from narratives of democratization into material spaces of science and practice, we can ask about lab interests, crop development projects, and researchers’ ambitions. How is the democratization of CRISPR produced by and seen in these institutional spaces? Will a democratized tool yield democratic seed?

IV. Democratization of crop development

From the start, the Innovative Genomics Institute has been interested in how CRISPR/Cas9 would go from a lab tool to making real world impacts. The impetus, Science Communications Manager Meghan Hochstrasser told me was — and remains — ambitious: “to try to solve the pressing problems of humanity using genome editing technologies.”

With plans to invest \$125 million in agriculture and microbiology over five years, the IGI began soliciting research proposals from scientists at Bay Area campuses in 2017, including UC Berkeley, UC Davis, and UC San Francisco. By 2019, the R&D network for agriculture enabled by and connected to the IGI had burgeoned. Fourteen main projects were funded, in areas ranging from basic discovery (exploring underlying mechanisms of plant immunity), to delivery tools (developing transgene-free expression systems) to applications of closer relevance to farmers and sustainable food systems (such as virus and fungus resistant cacao, bacteria-resistant tomato, rice with enhanced potassium-uptake efficiency). A multimillion-dollar Plant Genomics & Transformation Facility was up and running under the directorship of former DuPont Pioneer scientist Myeong-Je Cho, and several young technicians — many also from DuPont — were brought on board to help establish new genome editing protocols for a variety of crop species. Interviewed by *Business Insider* in April 2019, Doudna said: “I think in the next five years the most profound thing we’ll see in terms of CRISPR’s effects on people’s everyday lives will be in the agricultural sector” (Brodwin, 2019).

Democratization has not been quite the buzzword at IGI like it has in Barrangou’s circles at NC State. Yet the ethos clearly resonates with Doudna, who has spoken publicly on the democratization of CRISPR in the context of human gene editing (Shao and Pershad, 2019). It also appears to motivate Brian Staskawicz, a UC Berkeley professor of plant and microbial biology who directs the agricultural

arm of the IGI (**Figure 2**). Staskawicz told reporters on the day the agricultural program was launched that CRISPR-Cas9 could cut four to five years off of breeding cycles – saved time, researchers told me, that opens up the possibility for more and younger researchers to participate in significant research.

Alex Schultink, for example, a former postdoc in the Staskawicz group and currently an IGI Entrepreneurial Fellow, works on Bacterial Leaf spot in tomatoes. By using CRISPR to knock out key genes involved in the plant's immune response, Schultink was able to characterize which genes are essential for recognizing the invading bacteria's "effector proteins," and to subsequently engineer tomatoes with enhanced genetic resistance (Schultink et al., 2017). Schultink has already launched his own company, called Fortiphyte, founded in 2017 as part of his participation in the Entrepreneurial Fellows Program. After doing initial work in tomato, which resulted in the development of a tomato variety with resistance to several major bacterial pathogens, Fortiphyte has expanded to address disease issues in soybean – the most widely grown crop in the United States with nearly 90 million acres under cultivation.

Another Staskawicz lab member, Michael Gomez, has trained his energies on developing-country crops, specifically cassava. Growing up in a Colombian family, Gomez

told me, he was familiar with cassava as "yuca." But it was not until he came to Staskawicz's lab that he learned of its importance for African smallholders – where roughly 500 million people rely on the crop for a substantial portion of their nutrition. When Gomez entered the lab in 2013, "it was just after CRISPR kicked off," he told me. After "a good long sit down with Brian, [when] we talked about CRISPR, how exciting it was," Gomez decided to pursue a dissertation on cassava brown streak disease. A viral illness first reported in the 1930s in East Africa, "CBSD" has since spread to higher altitudes in Uganda, Kenya, Tanzania, Burundi, and the Democratic Republic of Congo. The pathogen can sometimes decimate the root crop below ground without farmers' even knowing it, Gomez told me – losses of up to 70% root weight have been reported, with an estimated \$175 million loss in east Africa each year. In a separate project, Gomez is using CRISPR-Cas9 to block cassava's production of cyanogens, which when over-consumed can contribute to a devastating paralytic disease. Preliminary successes in this project have already been published in peer review (Gomez et al., 2019).

Supporting the efforts of these young investigators is an army of staff who help get gene edits into plant cells. In both medicine and agriculture, a major problem facing the gene-editing field so far is *delivery* – the ability to get CRISPR-Cas9 into seeds to edit a plant's genome.

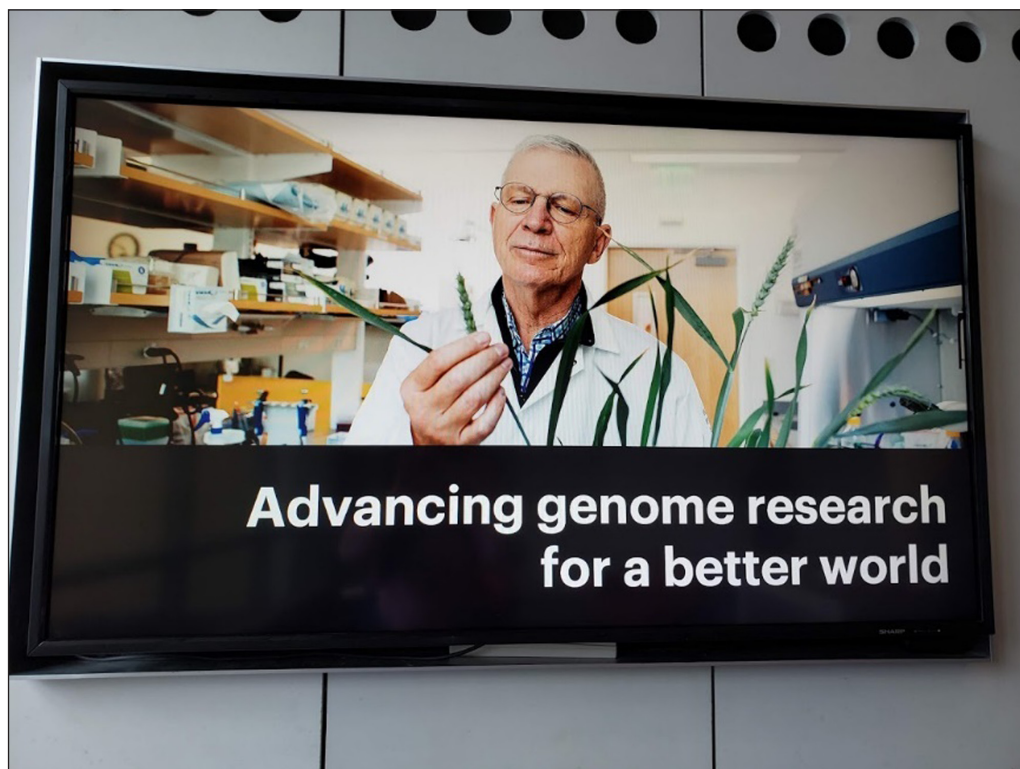


Figure 2: "Advancing genome research for a better world." The Innovative Genomics Institute, a partnership between the Universities of California at Berkeley and San Francisco, is an epicenter for gene editing research and development in biomedicine, microbiomes, and agriculture. Providing access to research tools is seen by the IGI as one aspect of CRISPR's "democratization." Another is focusing on crops that "feed the world," including major crops such as rice and wheat and, for developing countries, cassava and cacao. A rotating carousel of images on display in the lobby of the IGI depicts Brian Staskawicz – Maxine J. Elliot Professor of Plant and Microbial Biology at UC Berkeley and the IGI's Scientific Director of Agriculture – examining a spike of wheat. DOI: <https://doi.org/10.1525/elementa.405.f2>

Most labs currently use older GM techniques, based on *Agrobacterium*, to shuttle the genes for CRISPR and Cas into the plant cell. Once inside, the genes express the CRISPR RNA “guide” and the Cas9 enzyme, ready to do the gene editing. But that process also means the plant is transgenic – potentially triggering regulation. The IGI’s move to hire Myeong-Je Cho from DuPont was therefore an important step in supporting the larger plant breeding pipeline: Cho developed a way to shoot the CRISPR-Cas9 protein/RNA complex, fully assembled, directly into the plant cells, avoiding the need to use *Agrobacterium* upstream, and opening up possibilities for “transgene free” CRISPR crops.

Cutting-edge plant transformation, a deep field of young genome researchers, and the combination of existing plant breeding expertise with new agility granted by CRISPR-Cas tools are at the heart of IGI crop development. These dynamics could, of course, have more or less democratic results depending on the motivations and socio-technical lock-ins of the IGI and its backers.

How do IGI researchers and staff feel that CRISPR is, or could be, democratized via their work? My interviews pointed to four primary avenues. First is in expanding biotechnology to crops and traits of critical importance to farmers in developing countries. Whereas Green Revolution programs often displaced local cultivars with high-yielding modern hybrids and GM technology went primarily towards herbicide-tolerant and Bt crops of benefit to multinational corporations, several scientists expressed optimism that CRISPR could potentially be used in locally adapted subsistence varieties that have not been profitable for governments or companies to invest in. Gomez’s low-cyanogen and virus-resistant cassava,

for example, are principally being explored with an eye to smallholder farming systems in East Africa. A separate high-profile initiative at IGI is focused on developing gene-edited varieties of disease-resistant cacao for West Africa.

Institutional partnerships have been essential here: MARS, Inc., parent company of well-known brands such as M&M’s, Snickers, and Uncle Ben’s, is a major donor for IGI in general and for the cacao project specifically (IGI, 2018).⁷ The Donald Danforth Plant Science Center in St. Louis, Missouri – a non-profit research institute established with backing from the Danforth Foundation and the Monsanto Fund – supports the institute’s cassava research via collaborations with Danforth’s top plant breeders and access to its world-class cassava tissue culture and transformation facilities. For these and other reasons, IGI researchers told me, pop-science democratization memes often sound gimmicky and overblown. The knowledge-sharing, funding, and infrastructural resources required to produce a viable CRISPR cultivar are not easily found in anyone’s garage.

A second major aspect of democratization I heard about was access to methods of genome editing and plant transformation. The Plant Genomics and Transformation Facility vies to create novel, DNA-free methods for delivering CRISPR-Cas9 components into plant cells and making these and other plant breeding techniques “widely accessible to the world community” (IGI, 2019a). While it does not quite solve the garage problem, such efforts do take “access” beyond molecular tools for basic science and into the pragmatic techniques of plant breeding. A third way is through the IGI’s handling of intellectual property in the non-profit sector (see **Box 1**). While for commercial applications, the UC manages CRISPR-Cas licenses via

Box 1: Who owns CRISPR IP?

The question of intellectual property hovers insistently over any conversation about democracy, for the obvious reason that those who own a technology have a strong hand in shaping its outcomes. The IP question is also, unfortunately, not so easy to answer, since numbers of patent applications and awards grow incessantly, since IP can be claimed on CRISPR-Cas components, applications, vectors, and delivery, among other elements, and since a vicious 7-year battle over foundational CRISPR IP remains unsettled.

Despite their discovery in the 1980s in *E. Coli*, CRISPR sequences remained somewhat mysterious until the early 2000s, when Philip Horvath and Rodolphe Barrangou at Danisco (later acquired by DuPont) discovered in yogurt bacteria that CRISPRs were related to infection by viruses and subsequent immune defense (Barrangou et al., 2007). DuPont filed a number of patents on this technique, placing Danisco as one of the earliest CRISPR patent holders in the early CRISPR research history – yet for yogurt culturing, rather than genome editing (IPStudies, 2018).

IP rights on the genome editing tool came into the picture in 2012. At that time, two apparently independent discoveries kicked off a dispute that NYU patent expert Jacob Sherkow (2015) has called a “monumental event” in generating core CRISPR IP. Two principal research groups say the insight to use CRISPR-Cas9 in higher organisms was theirs first. One team was led by Doudna of the University of California and Emmanuelle Charpentier of Vienna University who filed a patent application in May outlining how CRISPR-Cas9 could be used to precisely cut isolated DNA in any organism (Jinek et al., 2012). The other team, led by Feng Zhang of the Harvard/MIT Broad Institute filed its first patent application in December, showing how the CRISPR-Cas9 system could be adapted to specifically edit DNA in eukaryotic cells such as plants, livestock, and humans (Cong et al., 2013). The Broad team also expedited their request, and because the US Patent Office had not yet switched to a “first-to-file” system (which occurred later in 2013), the first CRISPR patent was granted to the Broad Institute in 2014 (Sherkow, 2015; Ledford, 2016). To contest this decision, the UC filed what is known as an “interference claim.” *Continue reading here* [<https://doi.org/10.1525/elementa.405.s1>].

its spinoff Caribou Biosciences and Corteva Agriscience (which acquired exclusive cross-licensing rights from Caribou in 2015 as DuPont Pioneer), for non-commercial purposes, the UC offers free use of the technologies it controls. One way is through a cross-licensing framework established in 2017 between DuPont Pioneer and the Broad Institute which grants access to IP for CRISPR-Cas9 technology to universities and nonprofit organizations for academic research (Cameron, 2017). Another way is through Addgene, the clearinghouse for a range of CRISPR tools and reagents. Thus, many of the CRISPR innovations hatched at the IGI are effectively distributed free-of-charge to researchers around the world.

Fourth is in education and public outreach, through forums including journal clubs, student courses, symposia, lecture series, art programs, and public events. In 2019, for example, the IGI's offerings expanded into professional education with "CRISPR Genome Editing: Practical Aspects of Precision Biology" – a course that, in partnership with UC Berkeley Extension, mimics a summer undergraduate course on CRISPR, but is open to members of the public. A "CRISPR (un)commons" artists-in-residence program, launched in 2019, aims to connect graphic designers and multimedia artists with gene editors "to foster creative new perspectives, introduce CRISPR to broader audiences, and catalyze deeper engagement with the technology's fascinating implications" (IGI, 2019b).

Each of these elements incite further questions about what it means to democratize S&T and on whose terms. MARS, for example, is currently dealing with allegations of biopiracy from indigenous groups in Mexico, who claim their *olotón* corn was appropriated, if not illegally, then unjustly, and without wider community consent (Pskowski, 2019). The Danforth Center, supported by Monsanto/Bayer and the Gates Foundation, among others, has long been criticized by civil society groups for "top-down" approaches in its international breeding projects that tend to overlook the diversity of crops farmers are already growing (GRAIN, 2019). The IGI's own plant transformation labs, supported in part by MARS, illustrate the chasm between the CRISPR "recipe and ingredients" and the Michelin-star restaurant, to which access ain't cheap: \$40,000 for a fluorescence microscope, \$600 for a small tube of gold powder (actual gold) and \$30,000 for the DNA particle gun. In the basement, wheat grows in special chambers – each one costing at least \$100,000, according to Cho (Weinstein, 2017).

These public-private partnerships and the material resources they enable are hardly new to CRISPR. In the late 19th century, Buttel (2005, 276) shows, "productivist coalitions" had already begun forming amongst farm commodity groups, land-grant administrators, agribusiness firms, and federal agricultural agencies with the goal of increasing agricultural productivity, "to enable progressive farmers to modernize their way out of their problems." In the 1980s, the molecularization of biology dovetailed with the advent of utility patents on novel organisms (*Diamond v. Chakrabarty*) and the passage of the Bayh-Dole Act, fundamentally shifting incentive structures for research and deepening co-dependencies between public universities

and agribusiness (Eisenberg, 1996; Kloppenburg, 2004; Boettiger and Bennett, 2006; Glenna et al., 2007). By the 1990s, a study by two Cornell scientists found that land-grant researchers were even more likely to have closer relationships with the biotechnology industry than their counterparts at other research universities (Curry and Kenney, 1990; see also Busch and Lacy, 1983).

What is relatively new is the openness and apparent acceptability of industrial capital entering into university spaces. The Plant Genome Engineering Symposium, hosted annually at UC Berkeley and featuring many IGI researchers, is proudly supported by Corteva Agriscience (PGES, 2019), and Dow Chemical openly grants prizes and awards to promising young researchers in gene editing (Dinh, 2014; SISCA, 2019). Via the Entrepreneurs Fellowship, launched in 2017, the IGI works to nurture "business minded scientists" – in Doudna's words, to help them "get the head start needed to earn the confidence of investors" (IGI, 2017). Not least, there are IP ties: Corteva holds exclusive rights in row crop development and non-exclusive rights in other agricultural and industrial applications from the UC. These rights were obtained via a cross-licensing arrangement that DuPont signed in 2015 with Caribou Biosciences, a startup created by UC Berkeley to develop applications of its CRISPR-Cas systems (Egelie et al., 2016; Caribou, 2015; see **Box 1**).

In this context, it stands to reason that democratization is less frequently invoked in terms of civic agency, farmer participation, or the realignment of institutional practices and decision-making power. It means that the education initiatives, for example, tend to focus on distancing "precise" CRISPR from clunky GM and on defraying public skepticism seen as based on fear or misunderstanding of science. It means that genome editing and transformation tools are promoted as "widely accessible to the world community" but who comprises this world community is not itself the focus of scrutiny. It means that IP rights in the non-profit sector are emphasized as democratic, eclipsing a conversation about IP rights in the private sector, where rights for agricultural use have already been negotiated with the world's largest seed and chemical firms (Allen and Overy, 2017; Egelie et al., 2016; see **Box 1**).

Even in a research-oriented Society Program, an attempt by the IGI to recognize the impact that gene editing will have on society, there is slim recognition of democratization that percolates through institutional norms, practices, ethics, and research priorities in agriculture. This is not the case in medicine and health, where more robust conversations are underway. In the shadow of tremendous ferment over human germline editing, a group called the Berkeley Ethics and Regulation Group for Innovative Technologies (BERGIT), hosted by the Society Program, has been convening experts to discuss risk, costs of access, scientific boundaries, and human rights (see for eg., Halpern et al., 2019; Wilson and Carroll, 2019).⁸ IGI leadership has also been at the helm in organizing meetings with national academies from other countries, in which public dialogue and citizen participation, scientific and government accountability, and other democratic tenets are seen

as desirable. Yet a parallel conversation about agriculture has been hard to find, at least in public spaces.

In the lacuna of an audible dialogue about democratizing agriculture, there are, however, labs moving ahead in potentially game-changing work. One lab at UC Davis has taken on the enclosures of hybridization, plugging CRISPR into a system that could fundamentally reshape the political economy of seed.

Democratizing seed? A case of synthetic apomictic rice

Nearly 100 years ago, hybrid technologies first separated farmers from reproducing their own seeds (Kloppenborg, 2004). The transition from open-pollinated to F1 hybrid maize in the first few decades of the 20th century was both market-based and biologically driven (Duvick, 2001, Luby et al., 2015). On the biological side, plant breeders recognized that prolonged inbreeding of individual plants weakened them but also purged them of deleterious recessive alleles. When cross-bred, the two inbred lines produced offspring with “hybrid vigour” – higher yielding, more robust, and with more uniform traits.⁹ F1 hybrids became the dominant paradigm for modern crop breeding worldwide by the end of the century, introduced into hundreds of horticultural and grain crops amenable to the technique (Walker, 2004). The rub, of course, was that F1 hybrids do not “breed true” – the offspring inherit different combinations of genes than their parents, which means farmers wanting stable traits cannot save their seed.

Professor Sundaesan and his postdoc Imtiyaz Khanday at UC Davis believe they may have found a way to crack this enclosure. It relies on making exact replicas of hybrid plants from seeds without fertilization – in other words, cloning hybrid seed. Unlike most hybrids, these seeds can be saved reliably one year to the next, potentially putting their reproduction back into the hands and landscapes of farmers.

Khanday explains that the rice project did not initially have farmers in sight. The lab was interested in a basic science question of how zygotes develop. After an egg cell fuses with a sperm cell, how does the resulting zygote – an organism’s very first cell – begin growing? What are the maternal and paternal contributions to the process? These are not new scientific fascinations. Aristotle’s writings from 350 B.C. indicate that he believed the mother provides the “matter” while the father provides “form.” Ethel Harvey in 1937 performed experiments in sea urchins that suggested early embryogenesis depends only on maternal factors – and the mother’s sufficiency has since been a widely-accepted belief among scientists. Especially because a sperm cell’s DNA has to be tightly compacted for transportation, whereas the egg cell has loads of cytoplasm for carrying gene products, the long-held understanding was that sperm does not contribute anything to initial development.

But something called “Baby Boom” has recently upended that theory, at least in plants. The *BABY BOOM* family of plant genes, Sundaesan and Khanday have discovered, are expressed in sperm cells, but not in egg cells,

of plants including rice. In a series of experiments published in 2017, they showed that one of these genes, *BABY BOOM 1*, encodes a transcription factor which turns on in rice zygotes after fertilization – and that this expression can be traced to the male contribution to the genome. Continuing that line of logic, Sundaesan and Khanday took the next critical step. They reasoned that if *BABY BOOM 1* is the pivotal ingredient from the father, then by enabling the mother to make *BABY BOOM 1* on her own, they might no longer need the sperm at all – a *BABY BOOM*-mama might be able to get around fertilization.

Both researchers clarified that while this mechanism is original, the underlying idea is not new. People have been trying to propagate crops asexually – a process known as “apomixis” – for at least 50 years. Apomixis also happens in nature – over 300 wild species produce viable seeds without fertilization – but that process is poorly understood. Putting two and two together, breeders have attempted to breed apomictic wild relatives with crops like corn. Yet complications occur downstream when breeders must backcross the plants to remove unwanted wild traits. They often lose the apomictic trait completely. Therefore, Khanday explained, their lab came at this conundrum from the opposite direction. Rather than try to breed the apomixis trait into hybrid crops, they decided to start with the hybrid crops and with what they understood, namely sexual reproduction, to see if they could bypass the whole process of sexual reproduction. Could they make hybrids that clone their own seed?

Basic science in an applied world

When I met Sundaesan in his office at UC Davis, he began by apologizing for the coming interview. “What I might have to say to you is rather dull,” he said, since sustainable agriculture was not his primary focus or expertise. “My background is basic biology,” he said. “I’m really in a separate universe.” Universal divides notwithstanding, the anti-enclosure of saveable hybrids is something Sundaesan has known about for a long while. A colleague, Simon Chen, who passed away in 2013, had been working on the idea. Because of Simon, said Sundaesan, “I knew about the huge benefits to farmers in developing countries because hybrids would become affordable.”

Still, Sundaesan never imagined that he would take up that baton when the apomixis experiment began. It was not an agricultural problem they were thinking about. It was the problem of jumpstarting life. The product of all life processes in the end are the gametes, he told me. But gametes are “dead end cells.” So how do you go from dead ends to a cell that reproduces life? “This cell is almost magical,” he told me, eyes lighting up. “It has the capacity to make an entire organism.”

It has also been a tough problem for biologists to crack, both because egg cells are fantastically small, and because scientists suspected a complex network of factors might be involved in “zygotic transformation.” A breakthrough early on for Sundaesan’s team was the inkling that a few key genes might be kickstarting the process. Once they had narrowed the field down to *BABY BOOM*, they needed to test their theory about the Baby Boom mama. Using

conventional GM technology, they engineered an egg cell to express the male-given *BABY BOOM* factor. It worked.

“So this is a really novel mechanism, Khanday told me. “Nobody had thought about reproduction like this, like, you know, you can just essentially bypass a sperm cell fertilization for reproduction.” It was a major breakthrough for basic science, illuminating what Aristotle could not have foreseen. It was also pretty useless from a practical standpoint. Since this egg cell has not been fertilized, the seed it goes on to produce contains just half the number of normal chromosomes of a normal seed. “Virgin birth” was at that juncture just a nifty demonstration project.

All that changed when Sundaresan found himself in France, where he encountered a curious conference poster. A French lab presented evidence showing they could eliminate meiosis using CRISPR-Cas9.¹⁰ By turning off three genes – called *MiMe* – that are key for meiosis, they could produce gametes, both male and female, that have the full complement of chromosomes. “This is when the lightbulb went off,” Sundaresan told me. He had a *BABY BOOM* that could bypass fertilization, but only half the number of chromosomes. The French team had a way to double the chromosome number. If they could combine *MiMe* and *BABYBOOM*, they might achieve viable apomictic seed.

And that is exactly what happened. After the French team published their paper, the two labs agreed to collaborate, swapping their *BABY BOOM* and *MiMe* elements. As it turns out, waiting for the paperwork to import the French team’s *MiMe* mutants was more cumbersome than making a fresh batch, so Sundaresan’s lab used CRISPR to knock out the three *MiMe* genes in rice. Combining that process with the *BABY BOOM* expression, they achieved rice seeds that are both transgenic and gene-edited plus something that has never been seen before: a hybrid crop that can be saved by farmers, year after year.

Social implications of hybrid clonal rice

Days after Sundaresan’s team published their results, *Nature Biotechnology* ran a feature story that captured the potential magnitude of the event: “This technology will change the course of agriculture itself,” Jauhar Ali, a senior scientist at the International Rice Research Institute in Los Baños, Philippines, told the journal. “Many scientists have been working on this technology for two decades. This is exactly what we’ve been waiting for all these years (Waltz, 2019).”

Although the project did not begin with the objective to make saveable hybrid rice, the social implications were evident enough to Sundaresan’s team. “If we are successful in implementing it in the field,” Khanday told me, “smallholders will have to buy these seeds only in the beginning, and then they can keep them forever, right? So it’s going to basically free the farmers from the three companies that they have to buy seeds from every year.”

Seed companies could be expected to have a decidedly different opinion. But companies like Corteva Agriscience see a hefty silver lining on clonal seeds. Their own seed production costs could be much lower. Once a corporation gets a good hybrid, the plant could be engineered to

asexually produce seeds that are identical to the parent, eliminating the need to repeat the crossing of parent lines just to create F1 hybrid seeds.

Another allure for companies is the prospect of turning traditionally non-hybrid crops into hybrids. “I’m quite confident it will work in other cereals,” Sundaresan told me, based on the fact that *BABY BOOM*-like and *MiMe* genes are found in many cereal crops. Corn, because of its biology, was relatively easy to hybridize the old-fashioned way. Anyone who grew up in Iowa is likely to have had a summer job walking rows of corn to “detassel” female flowers. But crops like rice, soybeans, and wheat are not amenable to such techniques – and the prospect of expanding hybridization into those commodities is where companies see a real boon. Todd Jones, research director of crop genome engineering at Corteva Agriscience, told me that good candidates for apomixis are any “high-value crops that aren’t easily hybridized at the moment,” including commodity crops like wheat and soybeans for US and international markets. “That would be fantastic,” he said, “because right now, there is no good system for creating a hybrid soybean.”

Commodity crops, however, are hardly the limit. Jones indicated that Corteva is currently working on its own apomixis project in sorghum and cowpea, and he sees potential for Sundaresan’s process to work in subsistence crops like cassava. The utility, he suggested, goes beyond types of crops; it is about extending hybridization globally, to “any place you don’t have good systems for creating hybrid seeds” like those in the US. “I would compare it to the green revolution,” Ping Che, a research scientist at Corteva, told *Nature Biotechnology*. “This will probably be the second green revolution” (Waltz, 2019).

A new green revolution of clonal seed?

For decades, social scientists have poked holes in green revolution mythologies, pointing to geographic and class differentiation, alienation of cultural identities, and enduring metabolic rifts. At the height of the Cold War, “improved seed” – sponsored by international aid agencies, developed by crop-breeding science, backed by multinational agribusiness capital, approved by national governments, and promoted by armies of trained extension workers – arrived in villages from Mexico to India to the Philippines “carrying the aura of science and modernity” (Yapa, 1993, 264; see also Jennings, 1988; Wright, 2005; Cullather, 2010).

Widely touted as “scale neutral” – that is, of equal benefit to small- and large-scale farmers (Hazell et al., 2010) – high-yielding hybrids turned out to hinge substantially on farmers’ access to flat irrigated landholdings, chemical and fertilizer inputs, and money or credit with which to afford those inputs (Bernstein, 2010; Patel, 2013). Only a fraction of productivity now appears attributable to advanced genetics and breeding (Evenson and Gollin, 2003), and clearly “scale neutral” is not the same as “resource neutral.” Larger political-economic dynamics also factored in: As increasing yields put downward pressure on farm and food prices, adopters of hybrid seeds only benefited to the extent that their yields went up more than prices

declined. The result, Mazoyer and Roudart (2006) suggest, was a punishing “threshold of renewal” such that wealthier farmers tended to gain advantages relative to poorer farmers, widening existing socioeconomic inequity.

More recently, a burst of research from historians has forced a reappraisal of the situation facing countries like India in the 1970s (Stone, 2019). While conventional wisdom holds that India was on the precipice of famine, averted only thanks to Norman Borlaug’s dwarf breeds, new studies tell a different story. US food aid – not population growth – appears the likelier reason that India grew reliant on imported wheat during those decades. Prime Minister Nehru’s decision to accept wheat imports from the US kept food prices low for urban industrial workers but undercut Indian farmers and crippled domestic grain production. When that farming crisis escalated during the 1965–67 drought, demand for more wheat shipments clicked into gear with Malthusian logic: India was bursting with poor people, was running out of food, was clearly on the brink of an epic famine. Subsequent research, however, finds scant evidence of any excess mortality during those supposed famine years – Cullather’s *Hungry World*, Wise’s *Eating Tomorrow*, and five books/dissertations completed in the past few years (Saha, 2013; Subramanian, 2015; Baranski, 2015; Olsson, 2017; Siegel, 2018) collectively debunk the story of imminent starvation that Green Revolution seeds supposedly prevented.

What then, of CRISPR’d hybrid seeds? Sundaesan suggested that the yield benefits of such seed could still be tremendously beneficial for smallholders. “Hybrids,” he said, “have the potential to increase yields by 20–30% right away. But farmers won’t do it if they have to purchase seed – they are at the margins where every penny matters.”

This, then, is the critical question. Will farmers actually be able to save them? Should they want to? Have they participated in making decisions about developing these seeds? One wrinkle emerges from the ecology of planting clones. To hedge against the pest and disease resistances that might be incurred through large-scale sowing of clonal plants, Sundaesan envisions a need for many regionally specific hybrid rices. “It would not be one-hybrid-fits-all,” he assured me. Unlike the case of bananas, where 90% of bananas worldwide are one clonal variety – Cavendish, and before that, Gros Michel – Sundaesan envisions production of many localized hybrid rices. Different types are needed for Africa, Asia, and Latin America, he suggested. Different types for Northern India and Southern India. The geographic diversity will require greater diversity of apomictic rice plants.

The need for such diversification could also maintain farmers’ dependence on seed companies. Farmers can save these seeds, but they do not have the ability or expertise to make their own *BABY BOOM 1 + MiMe* synthetic apomicts. If democratization is at some level agency over food systems, including over seeds,¹¹ in this case, farmers are free to save and reproduce clones, but they are powerless to create new, adapt with, or co-evolve together with these seeds. Sundaesan concedes that the tension is real. He also hopes that the agronomic lifespan of the clonal

rice – he estimates 5 to 10 years – might still be better for farmers than the punishing annual cycle of purchasing F1 hybrids.

Intellectual property rights on clonal rice are the second major wrinkle, and raise questions about the extent to which these seeds are, or can be, democratized. The Regents of the University of California filed a US patent for “hybrid apomictic rice” on November 28, 2018 with a priority date of November 27, 2017. The UC has also applied for worldwide rights with the World Intellectual Property Organization (Khanday and Sundaesan, 2019). Across 202 pages of descriptions and drawings, the key IP protections can be found in ten claims written across the top. Nine of these claims cover plants – for example, “rice plants” and “cereal monocot plants.” A tenth claim covers process: the “method of making clonal progeny, the method comprising, allowing the plant of any of claims 1-8 to self-fertilize; and collecting clonal progeny from the plant.”

Jones of Corteva explains that companies like his would have to license Sundaesan’s apomixis process from the UC if they wanted to use this system, as written. “The alternative is to develop our own system that would not be dependent on the UC IPR,” he said. In either case, he confirmed, Corteva would not be precluded from patenting the results of their clonal seed production. Exceptions might include crops like cassava which could be distributed to farmers in poor countries under humanitarian licenses.

A third issue is whether and how farmers will be involved with decisions about hybrid clonal seed. Sundaesan told me the lab is currently in discussions with the International Rice Research Station (IRRI) at Los Baños in the Philippines to transfer the technology to actual hybrids that farmers can use. In addition, the researchers are open to working with a variety of seed companies interested in producing apomictic hybrids. In both scenarios, farm-ready clones are some ways off, since the lab has achieved only 30% efficiency in their experiments so far, and the goal is to go beyond 90%. At that point, Sundaesan suggested, IRRI should have conversations with farmers, and breeders are probably best equipped to have such discussion. He hoped farmers would be able to save their seed.

Given the history of Green Revolution science, we should be curious about the prospect of democratic conversations in this institutional space. The aura of science and modernity that accompanied high-yielding varieties in the 1970s hovers as strongly around CRISPR today. Will CGIAR centers that are increasingly reliant on private sector partnerships be able to hear “what farmers want”? Moreover, to paraphrase Stone and Flachs (2014), will they take seriously that “farmer voice” is strongly shaped by the initial information about a given technology to which farmers are exposed? Will companies and Green Revolution institutions be able to overcome the epistemological failures of modernist diffusion theory, which Yapa (1993) reminds us, have long erroneously constructed peasants who resist modern hybrids as “laggards” and ignorant “nonadopters”? (see also Glover et al., 2019).

Back at UC Davis, Khanday told me that no farmers have yet been involved in the hybrid clonal rice project.

Fair enough, as it started out as a basic science pursuit. But as Corteva Agriscience and IRRI begin the chain of applications – from further R&D on new crops, to field trials, market piloting, and commercialization – how the farmer and citizen voice gets heard becomes all the more important. Do rural communities have not only enough voice, but also as Goetz and Gaventa (2001) suggest, “the pre-conditions for ‘voice’ through awareness raising and the capacity to mobilize?” Will they be constructed as “laggards” or backwards people unless they want CRISPR seeds? Will they be asked to accept the boundaries of democracy offered?

Such questions connect sites of CRISPR research to policy and regulation. They invite us to look at public conversations around gene editing, whose voices are heard, and how power mediates the potential of democracy in decision-making spaces.

V. Governing CRISPR

The road to CRISPR governance began, you might say, in 1974, when the National Institutes of Health established a Recombinant DNA Advisory Committee (RAC) and charged it with developing and coordinating the implementation of federal guidelines for the conduct of recombinant DNA research (Kleinman, 2000). From the perspective of the NIH officials, the RAC was designed to be an “expert committee” (Wright, 1994, 165), in line with the pervasive ethos at the time, which suggested that in matters of genetic engineering research, only scientists were qualified to make judgements about health and environmental safety. This same logic infused the famed 1975 gathering at Asilomar, the conference center in California where biologists gathered to recommend guidelines for recombinant DNA experimentation.

By April 1976, public pressure had forced the NIH to include one nonscientist on the expert committee, and a second one by September of that year. Brought in “late in the policymaking process,” Wright argues, their effect was muted by being allowed to participate only “after a consensus on major policy issues had already been established” (Wright, 1994, 214). After publication of the formal NIH guidelines on rDNA prompted yet more civic protest, the committee rules were revised: 20% of its members going forward should be “persons knowledgeable in such matters as applicable law, standards of professional conduct and practice, public and occupational health, and environmental safety” (RAC, in Wright, 1994). Despite this opening, notes Wright (1994, 354), “its largest and most influential block” could be expected to support further relaxing of the NIH guidelines given that a solid majority had “primary professional ties to institutions engaged in biomedical research, including private industry.” Only a minority argued for cautious positions, while most committee members leaned toward “self-regulation” in research.

Fast-forward to 2019, and biotechnology crop governance in the US is remarkably unchanged. On June 5, the US Department of Agriculture (USDA) published a new draft rule that would allow developers to “self-determine” whether their biotech traits qualify for exemption from

regulation. The rule comes from the USDA’s Agricultural Plant Health Inspection Service (APHIS) and signals less an about-face than an inflection point in the regulatory approval of several new GE crops over the past ten years (Kuzma, 2016). CRISPR non-browning mushrooms and waxy corn, for example, were approved for commercial production in 2015 and 2016, respectively, and in early 2018 USDA Secretary Perdue clarified the agency’s stance on gene-edited crops more broadly: “Under its biotechnology regulations, USDA does not currently regulate, or have any plans to regulate plants that could otherwise have been developed through traditional breeding techniques as long as they are developed without the use of a plant pest as the donor or vector and they are not themselves plant pests” (USDA, 2018).

The 2019 APHIS rule goes farther, granting developers the authority to make a “self-determination” about whether new crops can be exempt from regulation. Grounds for exemption include several modifications that CRISPR excels at producing, such as crops with deletions of any size, single base pair substitutions, and introductions of sequences from related species (USDA/APHIS, 2019).¹² The proposed rule does not include “noxious weed” risks as a trigger for premarket regulation, relinquishing an area of oversight within the agency’s authority that would otherwise require it to consider weed-based risks posed by new gene-edited crops. And, responding to claims that requiring field trials and petitions for deregulation proposed in 2017 (USDA/APHIS, 2017) “would be too burdensome and had the potential to stifle innovation,” the proposed rule grandfathers in plant/trait/mechanism-of-action combinations reviewed by APHIS in the past.

With developers able to self-determine whether a crop fits any of these exemption categories (or else request a letter from APHIS to confirm that they are exempt), the new approach, according to Jennifer Kuzma, co-founder of the Genetic Engineering and Society Center at NC State, “is decidedly anti-regulation and pro-biotechnology” (Kuzma, 2019). Atop these imminent shifts, a new Executive Order from Trump’s White House pressures all three agencies involved in the Coordinated Framework for Regulation of Biotechnology¹³ in the US – the USDA, the Food and Drug Administration, and the Environmental Protection Agency – to “remove barriers that impede small, private United States developers, the United States Government, and academic institutions from bringing innovative and safe genome-edited-specialty-crop-plant products to the marketplace” (White House, 2019).

CRISPR is thus at the center of the largest overhaul of US federal guidelines in over 30 years. In the face of R&D investments that will imply sweeping changes to farming landscapes, food supplies, and international trade; federal agencies are relying on developers to self-determine the extent to which they are governed. Against this backdrop, numerous scientific and civil society groups are seeking alternative avenues in which to debate, discuss, and negotiate the risks and benefits of CRISPR technology.

One such arena is CRISPRcon, an annual conference whose stated mission is to “Bring together diverse voices to discuss the future of Gene Editing.” Organized by the

nonprofit Keystone Policy Center in Boulder, Colorado, CRISPRcon has drawn a variety of scientists, farmers, physicians, entrepreneurs, and bioethicists since the first event was held in Berkeley in 2017.

CRISPRcon moved to Wageningen, Netherlands in 2019, with a marked emphasis on agriculture. Julie Shapiro, Keystone Policy Director and lead organizer of CRISPRcon, told me that, in contrast to the 2018 Boston meeting where people were keen on health applications, “in the case of Wageningen, absolutely, we were in a setting of an agricultural research university, and that’s who we drew in terms of the audience.” It also took place, she said, against the backdrop of European Union court decisions about biotechnology, which inflected the conversations.

Prominent themes emerged during the first day’s keynote panel between Louise Fresco, president of Wageningen University & Research, and Johan van der Oost, a professor of microbiology at WUR and early pioneer in CRISPR science. Fresco set the tone by encouraging the audience to think not just about genetics, but whole food systems – which she sketched in terms of precision breeding and precision agriculture, supported by sufficient water and fertilizer. Property rights were also important, she argued, and the best of Plant Breeders Rights in the UPOV Convention should be combined with the best of patent rights under the WTO’s TRIPs to fairly compensate companies for their innovations without impeding breeders’ access to gene editing technology. When contemplating risks of CRISPR, she said, we must also consider the risks of limiting Europe scientifically. “The worst thing that can happen is that Europe is so far behind that it doesn’t understand anymore what kinds of innovations are being developed elsewhere.”

If losing a global competitive edge in biotech has become a familiar refrain within scientific academies and seed companies in both the US and Europe (NASEM, 2019; Plantum, 2019), more unusual was the emphasis both speakers placed on the need for public dialogue. Van der Oost – a recent recipient of the Spinoza Prize – described how he is using a portion of the award to support students and teachers to learn “what CRISPRcas9 is about and also how it is different from mutagenesis.” Fresco underlined “service to society,” which is “more than just communicating, because communicating still suggests that you are there to send a message. We are also here to listen, to listen to what happens in society.”

Post-conference feedback indicated that many people indeed appreciated the attention to inclusion and the diversity of views presented. Alfred Grand, an organic farmer from Austria, had shared on the opening panel – which included An Michiels, Syngenta’s new head of seeds development – his concerns about biodiversity and seed company market domination. “Don’t forget safer, ‘low-tech’ methods to get to our goals: [Want to] feed 8 billion people and stop climate change? Cut down food waste (currently at 40%), educate smallholder farmers (produce 70-80% of all food), eat a more plant-based diet.” On departing, he tweeted: “It was a pleasure and I am thankful for the opportunity to share my views! #CRISPRcon2019.”

A handful of participants, however, expressed misgivings about their CRISPRcon experience. Tom Wakeford of ETC Group and Alejandro Argumedo, director of Asociación ANDES, an indigenous rights organization in Peru, both told me they felt “tokenized” by a gathering in which only their two voices, plus Grand’s, represented critical views. “I think it was naive of Keystone,” Wakeford told me, to assume that Wageningen University – an institution renowned for its agro-industry pursuits – would produce anything other than a “trade show” for CRISPR technology. “Either they’ve gone in a very naive way or they knew that and somehow thought a few voices would provide balance,” he said.

In the days following the July event, Argumedo and Wakeford joined two academic researchers from the STEPS Centre at the University of Sussex to co-author a biting essay about CRISPRcon 2019. Titled “Choreographed Consensus,” the article argued that having just 3 critical voices out of 53 speakers curbed the likelihood that substantive concerns would be raised. An app-based system of audience participation further marginalized critical perspectives, they said, enabling panelists to address only questions that received the most “likes” from “the almost universally pro-CRISPR audience (Arora et al., 2019).” The authors also pointed to funding by corporations such as Bayer and Editas Medicine, industry associations including Plantum and the United Soybean Board, and research centers like the Innovative Genomics Institute and the Flemish Institute for Biotechnology.

When I spoke with Argumedo in July, it was already several weeks after his return from the Netherlands. Apologizing for the delay, he explained the local emergency: a mining concession was once again threatening the Potato Park, a collective of five indigenous communities in the Cuzco region that ANDES supports in their cultivation and defense of native seeds (**Figure 3**).

CRISPRcon, Argumedo told me, was a welcome opportunity to discuss the challenges facing indigenous peoples in centers of crop origin and diversity, like Andean Peru. For that reason, he had accepted Keystone’s invitation to join a panel on agriculture. But he came away disappointed, describing the event as a “parade of self-congratulation” that welcomed but did not legitimize the indigenous perspective. “In their view, indigenous peoples do not know how to develop our own seeds, he told me. “They don’t see us creating responses to our environment based on different ways of applying knowledge and information.” The old knowledge deficit model drives a familiar wedge between indigenous seeds (supposedly just “natural”) and CRISPR seeds (full of scientific expertise), while the democratizing narratives suggests something new: that everyone can be an expert, and achieve the latter. But, says, Argumedo, “gene editing is done more effectively by big corporations or research institutions. So farmers and indigenous peoples should be just the recipients of these goodies.”

Argumedo worried as well about the disconnect between discourses of democratization (“they used that word a lot,” he told me) and the scenario of CRISPR being



Figure 3: CRISPR-ing diversity? Social media followed Alejandro Argumedo of Asociación Andes at CRISPRcon 2019, as he responded to the suggestion that gene editing can contribute to enhancing agricultural biodiversity (credit: Nina Holland). DOI: <https://doi.org/10.1525/elementa.405.f3>

used “as a tool for extended domination by corporations and institutions” that marginalize the very genes and landscapes upon which they rely. He had gone to Wageningen, he told me, in an effort to discuss some of these concerns. But the forum, he felt, was boxed in by the boundaries of “democratization” that hosts, organizers, and most participants set. “We have to conform to their paradigm,” he said. “For me to have a valid view, I have to accept that modernity, scientific rationality, and rule of law based on associated intellectual property are the natural order of things. I have to accept this before I am allowed to talk.” In that context, he continued, “it’s very difficult to discuss democratizing technology, because it’s their technology, their interests, and their perspectives. Of course, they want to apply it to my benefit, they say.”

None of this has soured Argumedo on the need for continued dialogue at the intersection of indigenous knowledge and gene editing technologies. But, he stressed, “dialogue in a more democratic way – because right now we speak from their boundaries. The idea of democratizing science and technology is focused on *their* science and *their* technology, right?”

Power in participatory space

Space is a social product... it is not simply “there”, a neutral container waiting to be filled, but is a dynamic, humanly constructed means of control, and hence of domination, of power. (Lefebvre 1991: 24).

Political theorist John Gaventa reminds us that spaces for participation are not neutral but are themselves shaped by power relations. Crediting the run of French theorists (Lefebvre, Foucault, Bourdieu among others) whose canon connects concepts of space to power, he offers a “power cube” for analyzing how power shapes and is exerted in a particular space. It begins with boundaries, which delimit any given space. Power relations, in turn, are always shaping “the boundaries of participatory spaces, what is possible within them, and who may enter, with which identities, discourses and interests” (Gaventa, 2003, 8). Power relations can also help us analyze the transformative possibility of any given space. We might ask: How is the space created? What are the places and levels of engagement? To what extent is power visible? These questions constitute three axes of a power cube (Figure 4), the first of which (power in spaces) I use here to consider CRISPR governance.

Closed, invited, and created spaces

Especially with highly polarized topics like biotechnology, it is easy to bifurcate spaces of participation: pro-GMO and anti-GMO, inclusion and exclusion, hegemony and resistance. More nuanced accounts (eg. Felicien et al., 2018, Lapegna, 2016; Fitting, 2011; Levidow and Carr, 2010) encourage us to see that those who shape a particular space affect who has power within it – and that those who are powerful in one space may in fact be less powerful in another. Participatory governance work by Gaventa and colleagues over the years (Brock, Cornwall, and Gaventa, 2001; Gaventa and Pettit, 2011) provides us with a typology to evaluate how spaces are created,

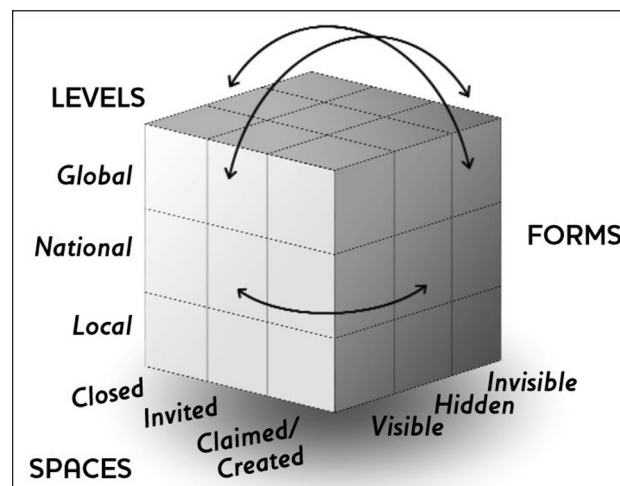


Figure 4: “The Power Cube” is a framework for analyzing the spaces, levels, and forms of power, and their inter-relationship. It is useful in helping us explore various aspects of power and how they interact with each other (Gaventa, 2006; see also www.powercube.net). Power in spaces is evaluated along lines of closed, invited, and created, which I use here to evaluate biotechnology governance. DOI: <https://doi.org/10.1525/elementa.405.f4>

whose interests are served, and what terms of engagement apply:

- A “closed” or “provided” space is one in which decisions are made by a set of actors behind closed doors, without any pretense of broadening the boundaries for inclusion. (In state governance, provided spaces are often those where elites provide services “to the people” without broader consultation or involvement).
- An “invited space” is one in which efforts are made to widen participation. People (eg. citizens or social movements) are invited to participate by various kinds of authorities, including government agencies, international governing bodies, or non-governmental organizations. They may be periodic or one-off forms of consultation.
- A “claimed” or “created” space upends the power balance of the previous two spaces. These are spaces claimed by less powerful actors from or against power holders. They may also be spaces created more autonomously by subaltern groups who are rejecting hegemonic spaces in favor of creating spaces for themselves (Gaventa, 2003).

With this model in mind, I suggest, it is possible to see the USDA/APHIS regulatory process, and the Coordinated Framework more generally, as emblematic of a closed space for coming CRISPR governance. For example, under APHIS rules (which govern the importation, interstate movement, or release into the environment of certain genetically modified organisms), the USDA Administrator has the ultimate authority to decide whether an organism will be regulated based on their review of the crop development process and judgement about the product – “if the Administrator has reason to believe the GE organism is a plant pest” (USDA/APHIS, 2019).¹⁴ Administrators also have the power to grant permits allowing such regulated articles to be introduced into the environment (under conditions the Administrator can specify) and to respond to developers’ petitions requesting non-regulated status. Public involvement does not come into play in decisions to allocate permits (see 7 CFR 340.4) and, for petitions, is restricted to a narrow comment period (see below). For roughly a quarter-century, this closed process has evidently worked to the benefit of developers. From 1992 until December 2018, the agency approved 130 of the 162 petitions for deregulation of GE products that were submitted by industry developers to the agency for review. The other 32 were voluntarily withdrawn (USDA/APHIS, 2019).

The new APHIS rule provides broad exemption categories for most GE and gene-edited crops (Kuzma, 2019). According to Steve Suppan, senior policy analyst for the Institute of Agriculture and Trade Policy, “input to develop the proposed rule occurred at private meetings with 80 organizations, with no public record of how these organizations influenced the content of the proposed rule. The private meetings with no public announcement are likely

illegal under the Administrative Procedures Act and other laws governing federal rulemaking” (Suppan, 2019).

Even more-centrist organizations known to support CRISPR applications in agriculture have been unimpressed by the opacity of current US regulatory systems. Greg Jaffe, Biotechnology Director at the Center for Science in the Public Interest, wrote in June 2019:

[N]o attempt at streamlining the work of biotechnology regulators at the Food and Drug Administration, the U.S. Department of Agriculture, and the Environmental Protection Agency should come at the expense of safety. The Executive Order is devoid of details and we fear it is a blank check for the three regulatory agencies to deregulate whole categories of products. We see this already occurring when last week USDA proposed revisions to their oversight, significantly decreasing the number of ag biotech products it will regulate going forward and allowing the industry to self-determine whether products are subject to regulation (Jaffe, 2019).

In comparison to this closed federal system, CRISPRcon appears to function as an invited space for biotechnology dialogues, if not formal assessment. Civil society leaders, small-scale farmers, and indigenous peoples are invited to participate; they are recognized and celebrated for adding representational and epistemic diversity; they are even recruited with an uncommon energy and commitment that I witnessed as part of the panelist-outreach process. “The conference organizers did a great job in creating an apparent diversity of voices,” Barbara Van Dyck of STEPS, who attended the conference, told me. “The various panels represented voices from people of different genders, geographical representation, ethnic backgrounds, religious beliefs and professional occupations.” Yet, she continued, “panel participants seemed to have been carefully selected for their convictions and positions which were all - apart from three exceptions – strongly pro-gene editing.” The majority, she said, expressed “strong opposition to the regulation of gene edited products in Europe following the EU directive for genetically modified organisms. Despite the apparent diversity, many voices were thus not represented on the panels.” As Argumedo put it: “So though they invite you to go into their space and they may accept that this difference exists, the message is very clear you are illegitimate. Your point of view doesn’t deserve much respect.”

Shapiro acknowledged that sharp contrasts had been a challenge to draw out in Wageningen, and participants indicated they “would have loved to hear more of the disagreement and would have liked to draw out their perspectives on stage more.” She also indicated that Keystone does not invite participants exclusively on the basis of “pro” or “anti” positions – people may be agnostic, see risks in some arenas and benefits in others, or be coming to the conversation for the first time. The rub, she observed, is that there is a natural audience base for events like these. “Those who are most plugged into the

topic of CRISPR – whether frankly it is for or against – can be easier to attract because those are folks who are focused on the topic and sometimes they already have positions formed,” Shapiro said.

Those who are plugged into CRISPR are also very plugged into carving the new technology away from the past. “It went wrong with GMO,” said Fresco, eliciting nods from all on stage. Several speakers in Wageningen invoked democracy in knowledge production and argued the need to move beyond the “information deficit” model towards more engaged communication. “You cannot have impact,” said Fresco in her opening remarks, “if you do not listen to what happens in society.” In both content and form, one could see CRISPRcon’s attempt to host a dialogue in ways that were not seeking to derive consensus or arrive at a certain view, but instead, were simply providing a forum for a broad set of perspectives to meet.

Van Dyck, Argumedo, and Wakeford, however, perceived something qualitatively different at play here, in which participatory techniques were advanced in support of a dominant point of view, and where “democracy” was bounded by distinct structural and ideological criteria: the privilege of Western technoscience, a rule of law based on private property rights, and a productivist approach widely regarded as self-evidently correct. These in turn underlay an analysis of problems and proposed solutions that are anything but a clean break from the past: if many people today are hungry, then all efforts must go towards growing more food on less land, using all forms of modern technology available. CRISPR fits beautifully into a compelling narrative that has haunted us since Malthus.

Yet the Malthusians have learned that rather than treat the public like ignorant subjects, it helps to cock an ear. Hence, said Van Dyck, techniques such as crowdsourced questions, which were used to generate an inclusive, engaged feel. Audience members could ask questions through an online app, which could then be “liked” by other members of the audience, and the most popular questions would be posed to panelists. The problem, she said, was that “critical questions were quickly buried under less politically sensitive questions receiving numerous likes.” A putatively democratizing app technology in this instance worked to marginalize minority perspectives as “fringe,” atypical, and anomalous within a much larger mainstream.

Shapiro told me that Keystone was responding to concerns about audience polling by supplementing the app with manual screening to allow more critical questions to be heard. I witnessed the system working better at the next CRISPRcon – held in Madison, Wisconsin in October 2019. In fact, because of this opening, some participants’ frustration with the debate’s framing became more evident to all in the room. At one point, Joseph Yracheta, senior scientist for the Native BioData Consortium and a Native American of Mexican origin (P’urhepecha and Raramuri), took the microphone to challenge the keynote speaker’s emphasis on the power of personal stories – stories in the face of which you cannot ethically refuse to alleviate suffering by using gene editing. Yracheta, who is studying health disparities among Native Americans at

Johns Hopkins, launched into a full pre-Colombian-contact reminder of where genetic diversity in food systems come from, whose knowledge is etched into the DNA of every CRISPR crop, and whose bodies may be sites of bio-prospecting for traits that are useful in gene therapies – and patentable by pharmaceutical companies. *Collective histories* like these, he suggested, and not just personal narratives, also matter.

Both Yracheta and Argumedo of course face the sizeable twin challenges of being technology critics in a world in which that role – unlike that of the “literary critic” – has fallen out of fashion (Parthasarathy and Stilgoe, 2019) and of being Indigenous in a world whose logics and underlying belief systems frequently antagonize their own. Biotechnology, and especially now CRISPR, is once again creating space to wrestle with evolving questions at the heart of democracy: the sanctity of intellectual property, tensions between individual rights and social justice, consent of the governed, rights and integrities of non-human life, the ethics and responsibilities of science in society. A brief recollection of this history is therefore essential for moving forward.

Biotechnology as a space for working through democracy

Liberal idylls and biotechnology share a past. While the Malthusian specter of runaway population and food scarcity resurged in the 1970s, the early heady days of recombinant DNA were gripping the scientific imagination. Much as with CRISPR-Cas9 today, people were asking: Who should be responsible for making decisions about this new technology that is radically transforming the economic and social practices of science? Then as now, people wondered who should be in the driver’s seat as “ivory tower rDNA morphed into a multibillion-dollar technological enterprise built on individual entrepreneurship, venture capital, start-ups, and wide-ranging university-industry collaborations” (Jasanoff, Hurlbut, and Saha, 2015).

Scientists figured it should be scientists. Who better than molecular biologist, they felt, to undertake comprehensive studies of biotechnology and its implications – and to issue governance guidelines based on responsible science? This Asilomar model is alive still today, as seen in 2015 when a small elite group of researchers gathered in Napa Valley to “to discuss the bioethical issues raised by the explosion in new genomic editing methods” (Greely, 2015). The organizers and attendees included CRISPR co-inventor Doudna, as well as Asilomar conveners and Nobel Laureates David Baltimore and Paul Berg. Though the gathering in 2015 included more diverse perspectives than in 1975, the prevailing air in Napa was not far from that of the first meeting enthusiastically depicted by Berg (2008) as paving the way for “geneticists to push research to its limits without endangering public health.”

Pushing research to its limits, of course, meant that what Asilomar mostly accomplished was the adoption of a containment principle, a system of physical and biological controls to keep organisms safely enclosed in experimental spaces. Unwilling to face perceived constraints on

“academic freedom,” larger scale social and ecological risks were left unaddressed. Asilomar did not consider the question of deliberate release of GM organisms outside the lab, which, twenty years later, as the first genetically modified crops started coming into US agricultural supply chains, seemed both absurd and extremely logical. The reaction from the scientific community was that these risks were outside of their domain.

Ecologists and farmers around the world, of course, could see the writing on the wall when it came to containment. As importantly, a wide range of publics – from urban mothers in Napa County to rural communities across Latin America – started mobilizing support through broader arguments: that GM crops were feeding more cars and cattle than people; that overall pesticide use was going up instead of down; that human and environmental health, biodiversity, and climate were being adversely affected; and that the concentration of power among ever fewer seed and chemical companies was “risky” and “unsafe” – but not captured by the formal and technical language of safety and risk.

One effect of this exclusion was that debates over the risk and safety of GM crops became a proxy for a host of other unacknowledged concerns (Gaskell et al., 2004). Kinchy’s (2012) vivid account of farmers and anti-biotech activists in Mexico and Canada shows how struggles over corn and canola, respectively, represent a “scientization” of public debate around the contamination of crops from seed mixing and pollen drift. One effect of this scientization, she argues, is that our frame of debate has been collapsed. We ask: “Is there sufficient evidence of biophysical harm from this particular agricultural technology?” Rather than: “What is the purpose or end goal of this technology?” or “What kind of world or type of agriculture do we want?” (Teller, 2014).

Kinchy’s farmers and activists confront this scientization by performing their own research, questioning regulatory science in court, enrolling international experts to back their efforts, and demanding that their governments consider social and environmental impacts of new technologies. The North American movement, as her research and others’ shows, has had a particularly strong emphasis on genes “out of place” – that is, the flows of transgenes across borders and the market, cultural, and ethical consequences of such genetic (re)placement (Fitting, 2011; Brown, 2013; Wise, 2019). In Western Europe, where anti-biotech activism has arguably been most intense and sustained, critiques have long centered on landscapes and bodies, motivating consumer avoidance of GM foods and a strong non-GMO organic sector (Schurman and Munro, 2003). In the Global South, by contrast, contestations have often focused both on gene flow *in* (contamination of native cultivars) and gene flow *out* (bioprospecting, or appropriation of seeds and biological resources from peasant farmers and Indigenous communities). Inseparable from resistances to biotechnology in the Global South have been resistances to the expansion of neoliberal policies and practices. A global regulatory regime advanced by institutions favoring market liberalization, free trade, intellectual property rights, and harmonized approaches

to assessing risk ushered in agricultural restructuring and transnational trade in GM crops – and birthed organized peasant movements to counter what was experienced as a loss of food and seed sovereignty (Pechlaner and Otero, 2008; Fairbairn, 2010; GRAIN and LVC, 2015).

From high-profile destruction of GM test plots to quieter struggles in litigation, regulation, standards, education, and policy, social scientists continue to document numerous arenas of struggle and forms of resistance to biotechnology that are important for understanding just what “democratization” of technology means, or would achieve. In this way, argues Jasanoff (2005), biotechnology isn’t just a development that polarizes society. Its design, regulation, and contestation are key arenas in which 21st century mechanisms of governance are getting worked out, and worked through. As a space in which the social compact between science and society is continually evolving, biotechnology opens up new possibilities for democratic theory and practice, including citizenship, deliberation, and accountability. Nation-building projects, as seen in the current CRISPR race between the US and China (Servando, 2019), show how biotechnology is incorporated into what a nation is imagined to stand for. Political culture provides another window onto democratic prospects, with citizens and other publics playing distinctive roles in evaluating the products of scientific knowledge.

Here, the well-documented divergence between the US and Europe in biotechnology regulation says much about the *laissez-faire* politics of the former’s institutions in contrast to the precautionary politics of the latter’s. Whereas the US developed product-based regulations based on perceived “substantial equivalence,” Europe has long held a regulatory system based on the precautionary principle, in which the process of genetic modification is seen as an appropriate basis for policy (Jasanoff, 2005; Wynne, 2001). This difference means, among other things, that citizens exert some political power through the state over biotechnology entering into their lives. By contrast, in the US, and in countries following its model, corporations’ rights to introduce new technological innovations have been harder to challenge.

Creating spaces for epistemic justice

It is no wonder, given the histories of institutions and countries where CRISPR-cas9 was developed, that its democratization is fraught with contradictions and imperfections. From the view of the power cube, much current governance occurs in closed decision-making spaces and fora where conflict is rendered invisible. Efforts to open those spaces, as seen with CRISPRcon, can struggle mightily against the inertia of scientific authority, institutional biases, and “buried epistemologies” (Braun, 1997) that combine to stymie the grappling with dissent necessary for deep democratic practice. By the same token, attention to these intersections of power and space in democratizing science can also contribute to new possibilities for challenging hegemonic power relations. Cracking open previously closed spaces could contribute to new science-movement partnerships and even “ConCiencias,” which

could wedge open those spaces yet more widely (Meek, 2018; **Figure 5**). Power gained in one space, Gaventa (2003) suggests, may also be used to enter new spaces, offering new entry points for transformational change.

STS scholarship has amassed numerous examples of such democratizations in practice. Steven Epstein (1995) discusses how AIDS treatment activism in the US has been a tool for grassroots mobilization to challenge the social organization of expertise. Richard Sclove (1995) traces the roots of “consensus conferences” in Denmark, where the practical mechanics of providing evidence are granted to laypeople who can and do grapple intelligently with highly technical matters that influence decision-making. Daniel Kleinman (2000) recalls a “citizen jury” that formed in Cambridge, Massachusetts during the early days of gene splicing research. Jurors heard from, and asked questions of, both genetic scientists and concerned citizens – a technique Michel Pimbert and colleagues (2001) follow in the context of GMOs and smallholder jurors in contemporary India. Participatory budgeting, citizens juries and assemblies, food policy councils, and participatory action research (PAR), among others, have all been explored as avenues for combining elements of deliberative and participatory democracy in the context of science and food systems (Powell and Kleinman, 2008; Philbrick and Barandiaran, 2009; Aasen and Vatn, 2013; Carlson

and Chappell, 2015; Méndez et al. 2016). PAR and other decolonial methodologies have gone especially far toward addressing issues of power inequality between Western scientism and knowledge systems systematically suppressed during European colonialism (Freire, 1970, 2014; Dussel, 1985, 2013; Mignolo and Escobar, 2013; Wakeford and Sanchez Rodrigues, 2018).

What is important across these cases, as Jasanoff (2017, 274) discusses, is that participants are not merely recipients of others’ wisdom:

STS’s attentiveness to multiple, coexisting knowledge regimes and rationalities complicates earlier understandings of citizens as either permanently clueless or eternally educable. It opens up a third possibility: the *knowledgeable public* that can process information, learn, and produce or enroll expertise when the situation demands...Indeed citizens as lay experts are entitled to *epistemic justice* (Visvanathan 2005), that is, a measure of respect for the experiential knowledge they bring to politics.

Visvanathan developed “cognitive justice” (2009) and the related “epistemic justice” (2005) to describe processes whereby societies attempt to recover systems of knowl-



Figure 5: ConCiencias as a “created space” for decolonizing science and nurturing epistemic justice. The Zapatistas of southern Mexico have long been concerned that entanglements of science and capitalism are producing human and environmental crises, palpably felt by frontline and indigenous communities like theirs. They also believe, however, that science can be reimagined – “towards a system of knowledge production that is humanized, which has a transformative social purpose” (Meek, 2018). In that spirit, “ConCiencias” – a term that translates literally as “with science” but also means “awareness” – was born. At the second ConCiencias conference in 2017, the Zapatistas invited 50 scientists from Europe, North America, and Latin America to their autonomous territories for four days of critical dialogue on the history of science and explorations of its counter-hegemonic potential. From talks on Occam’s razor, genetics, and technology to apiculture, agroecology, and food sovereignty, ConCiencias exemplifies a “created space” within which social movements and scientists co-create the visions, practices, and strategies of achieving epistemic justice. (*Left*: Zapatista women taking notes at ConCiencias. *Right*: Scientists John Vandermeer and Ivette Perfecto (University of Michigan) discuss the transformative potential of agroecology; Photo credits: David Meek). DOI: <https://doi.org/10.1525/elementa.405.f5>

edge that have been lost or degraded by scientism and its violent cousin, colonialism. The right of colonized peoples to use alternative ways of knowing about themselves and the environment is thus a way to survive the assaults of colonization, and, to borrow from Thomas Teo (2008), to fend against the pathologization of marginalized communities by academics whose findings overlook or ignore structural injustice as a cause of oppression.

Applied to CRISPR, these principles of epistemic justice can be combined with the lessons of the power cube to suggest a possible way forward. Created spaces of participation, and actively visibilized power relations can be anchors for enabling epistemic justice to occur. A knowledgeable public can, in turn, fortify the relationships and institutions through which community-to-research ties are forged, counter-hegemonic spaces are created, and the voices of often-invisible actors are legitimized in given spaces and places.

If it sounds like a pipedream, it helps to look South, where experiments in technology democracy are well underway. A group called Red de Evaluación Social de Tecnologías America Latina (Red-TECLA) has been working since 2008 to develop civil society-led assessments of technologies such as genetically modified crops. Supported by food sovereignty and agroecology movements, including La Via Campesina, ETC Group, GRAIN, and CLOC-LVC¹⁵ among others, the network started in Mexico due to growing concerns about transgenic maize, and has steadily sought to establish participatory processes for technology evaluations that would involve peasant farmers, indigenous communities, women and men, in countries such as Brazil, Mexico, Bolivia, Argentina, and Uruguay.

At the simplest level, such processes involve citizen-led adjudication. Actors hoping to introduce an agricultural technology come into a community and lay out their case in front of a panel of experts – from rural communities, and sometimes also consumers from urban areas. Promoters of the technology have the opportunity to describe what their product offers, and in turn, they must listen to questions from the community members and be open to cross-examination. Critics of *those* perspectives have a chance to raise questions as well. Then the group comes to some conclusions about the appropriateness of a technology for a given community and their agronomic, economic, and/or sustenance needs. Mechanisms are usually devised for environmental monitoring and assessment, allowing for iterative feedback with technology developers over time. The right to refuse a technology at any point – for example, if evidence of social or ecological harm unpredicted at the start should arise later – anchors the process in “technological sovereignty,” putting the right to *not* access a technology on par with rights of access.

Such co-creative processes and others like it (see “ConCiencias,” **Figure 5**) have begun to dissolve the hard epistemic lines between lay and expert in biotechnology policy and governance. Precisely because the power in created spaces is held by communities typically deemed inexpert and marginal, a window is opened for mutually transformative learning to occur. In that space, there is not only the potential to unseat the dominance of dominant

worldviews but for a knowledge-producing entanglement to occur – in which multiple, partial, and diverse perspectives achieve a more robust (and just) objectivity.

Towards generalizing the strategies of Red-TECLA, I offer the following principles and practices of CRISPR governance. They are based on lessons derived from STS scholarship on improving the democratic relationship between science and society. They are inspired by PAR and decolonizing scholarships’ experiences with strategies such as collective learning, experiential education, social movement gatherings, participatory on-farm research, farmer-to-farmer learning, community review, critical pedagogy, and, central to many of these, self-reflection (PKEC, 2017). Far from being complete or all-encompassing, they are an attempt to foreground epistemic justice and power in created spaces as a starting point for others to learn from and build upon.

Principles & practices for democratizing CRISPR

Redistributing value

Vannevar Bush’s “Science, the Endless Frontier” (1945) called on scientists to deliver new knowledge, seemingly untethered from the messy world of political and social problems. “Academic freedom” to innovate thus appears consonant with a liberal credo of democracy advanced by producing more knowledge and technologies based on it. Yet the commercial apparatus of twenty-first century science sheds a different light on such freedom. As publicly funded research institutions have come to rely on licensing their inventions to the private sector, market value rather than public good plays an ever stronger role in structuring priorities and incentives in research. In parallel, the flow of value from land to lab in plant biotechnology remains extractive – an accumulation of knowledge and materials from local communities and landscapes as genome editors seek further resources to “improve.” Academic freedom, in this way, has come to defend market freedoms more so than the public good. CRISPR will exacerbate this dynamic in the name of democracy unless we move to re-establish a “public interest” social contract between science and society. Where and to whom does value flow when genetic resources are tapped in the name of sustainable agriculture? Can we revive alternatives to intellectual property based on commons, open source, and other models of non-proprietary sharing and use? What are all the ways in which biotechnology can sustain a political economy of invention that fights social inequality rather than produces it?

Including the excluded

It is not enough to promote public engagement in biotechnology issues. Epistemic justice suggests that the poor, the historically marginalized, and the socially excluded must participate in meaningful ways to make decisions about biotech research, investment, regulation, and their intersections with farm and food policy. Doing so recognizes that those who stand to benefit most from a technology should engage with those who may be adversely affected by it. It also reveals the global heterogeneity in who is at risk and how risk is defined (Soleri et al., 2005; Fitting, 2011;

Kinchy, 2012), while allowing for the articulation of new meanings through deliberation on the distinctive questions that new technologies bring into being (Macnaghten and Habets, in review). Inclusion carries many pitfalls and contradictions to which we must also attend. It asks for attention to asymmetries of power and status in participatory spaces; gender, race, ethnicity, nationality all condition who “gets to speak.” It requires sensitivity to the possibilities of “tokenization,” where diverse voices are included only to be de-legitimated or cast as fringe. Inclusion also demands keen attention to the politics of representation, including who is speaking on behalf of larger bodies of communities and constituents. On what basis are spokespersons chosen to represent “farmer” or “African” or “Indigenous” perspectives? To mitigate the likelihood that inclusion serves as legitimation, Callon (2009) provides suggestions for good practice, including intensity, openness, and quality. These practices can complement what created spaces provide: a hedge against dissident voices being included under conditions and on terms not of their own making. Finally, we should be wary of what Nancy Fraser (2017) refers to as “progressive neoliberalism” — where amidst buzz of inclusivity and multiculturalism, we achieve “the rise of a small elite of ‘talented’ women, minorities, and gays in the winner-takes-all corporate hierarchy instead of with the latter’s abolition.”

Living in real world conditions

“Revolutionary moments do not reveal the future with map-like clarity,” argue Jasanoff, Hurlbut, and Saha (2015). This awareness is a call for an anticipatory approach, receptive to the contingencies and always ongoing uncertainties of science and technology that are shaping — and being shaped by — a complex stochastic world. It is even more importantly the understanding that living well with technology involves more than reacting to information about it. “Changes in social interactions and relationships with technology are unpredictable and emerge only through long-term experiences in varied settings. The stakes cannot be accessed, let alone addressed, in highly scripted deliberations that “engage” a limited range of citizens in terms that are defined in advance” (ibid). For CRISPR, the unscripted, long-term, and in situ experiences suggest looking to where RNA and DNA gives way to seeds, where seeds take root in living landscapes, and where communities of living organisms, including people, exert pressure on “what works” to sustain us. Participatory on-farm research, participatory plant breeding, and experiential education that involve farmers and gene editors as co-learners offer avenues for engagement in real world conditions.

Understanding sovereignty

A large literature on food and seed sovereignty exists, which biotechnologists could be more familiar with. As taken up by academics, governments, and social movements, food sovereignty has come to mean a wide range of things at different spatial and social scales (Iles and Montenegro de Wit, 2015). But what tends to unite them is decision making power: The right of peoples to deter-

mine their own agriculture and food policies, to organize systems of production and consumption to meet local needs, and to secure access to land, water, and seed. (Wittman et al., 2010; see also Nyéleni, 2007; Patel, 2009; Edelman, 2014; Trauger, 2017). Why should genome editors care? Partly, I suggest, because what is very often perceived as public ignorance about biotechnology is in fact a clash of paradigms — understandings about what “sustainable agriculture means” and who and what should be sustained.

Gene editing has quickly become subsumed into Sustainable Intensification, for example, a category of approaches that privilege technological and productivity-oriented innovations in order to improve resource efficiency while reducing the negative environmental and health impacts of current food systems (HLPE, 2019). Starting from a premise that yield per unit of land needs to increase (Pretty et al., 2018), SI typically does not seek to shift the political economies in which food systems are embedded. By contrast, agroecological approaches favor “territorially-specific visions, taking into account environmental, health, social and cultural conditions in a given location. They give a central place to the social, cultural and political dimensions of transitions towards sustainable food systems, to power dynamics and governance issues.” (HLPE 2019, 61). The point here is not to suggest one approach is better than the other, but simply to indicate that struggles over biotechnologies frequently indicate the degree to which science is recognized as political — as co-producing the social order through which sustainable food systems are imagined and realized.

Reckoning and repair

Even well-intended programs for public education about CRISPR often assume public ignorance. They fail to recognize widely held (if uneven) knowledge about the historical, embodied, and lived experiences of people with biotechnologies. From biodiverse pampas converted to soybean plantations to farmworkers’ bodies bearing chemical burdens to cultural/traditional practices disrupted or displaced — these are the “risks” that rural people know about because these changes have all happened, not because people do not understand. For every benefit in terms of yield, income, or nutrition that has been claimed (and those should be acknowledged), social and environmental costs that fall outside of a neat economic calculus have been snubbed or overlooked. When scientists not only fail to acknowledge, let alone take responsibility for, these effects of the past, the promises for shiny CRISPR futures ring hollow. Sensitivity to reckoning and repair asks that we respect a nation’s or community’s sovereign right of refusal. In the face of new technologies, as Tom Wakeford reminded us, we must include the choice to say no to particular visions of progress.

Expanding the aperture of possibilities

When we contemplate a biotechnological solution, what is the possibility space afforded? When appraising gene drives, the European Network of Scientists for Social and Environmental Responsibility suggests that we should not

just openly and inclusively consider gene drives themselves but should also evaluate the range of alternative ways of formulating and framing the problems that the technology is claimed to address (ENSSER, 2019). Likewise in other applications of CRISPR where alternative framings of problems (e.g. pest control vs. insect balance) will encourage discussion of a range of alternative approaches to solving them. Alternatives may carry fewer risks, may be more actionable in the short-term, may be more sensitive to local needs and resources and/or may better align with a diverse range of worldviews. Rather than foreclose upon possibilities and pathways of sustainability, we should be considering solutions that open them up.

Practicing reflexivity

In matters of technology, one informant told me, “I am most afraid of those who think they know everything.” Reflexivity is a call, borrowed from Wynne (1993, 2002) and Macnaghten and Habets (in review), to turn the magnifying glass into a mirror, to examine our own biases and assumptions, and to engage one another with curiosity and humility. Being open to being “wrong” is in this way an opportunity to rediscover the incomplete, partial nature of all of our knowledges – the mutual articulation of which comes closer to being “right.”

Being accountable

No technology, old or new, should be put out into the world with no system of accountability, no-one bearing the responsibility for social and environmental consequences. Different designs exist for accountability and responsiveness in technology, including proposals for tiered relaxation of regulatory regimes only in the context of agreement on societal benefit, sustainability, and ethics. Stilgoe et al. (2013) describe techniques that can facilitate enhanced responsiveness such as innovative uses of standards, open access and other mechanisms of transparency, the use of moratoriums, and alternative intellectual property regimes. Accountability can also take the form of research managers and science policy organizations engaging directly in processes of community review with farmers, consumers, and workers across the supply chain in the real-world contexts where technologies make their imprint. Rather than be seen as a punitive measure, accountability enables us to monitor progress – or lack thereof – on the above elements, which in the end is both a more rigorous approach to technology assessment and a way to build public trust.

VI. Conclusions

In the highlands of Peru, most smallholders have never the word “CRISPR,” let alone been invited to deliberate on it. In labs and industry spaces around the world, where CRISPR is ubiquitous, scientists and investors speak of a technology that will feed the world and make for more resilient agricultures, including climate-vulnerable landscapes like those of Andean Peru. In the gap between those communities is the potential for many things: participatory technology assessments, citizen-responsive regulation, education that recognizes different partial knowl-

edges on all sides. There is also the potential for industry self-determined governance, gene flow into native cultivars, bioprospecting from landraces – and the more prosaic risk that CRISPR is not terribly useful for the problems at hand. “Because of the mining companies that come and destroy the whole ecosystem, I might have to migrate to a city,” said Argumedo, “If I lose my land, I can’t do agriculture at all. So, CRISPR, I don’t think it is going to make any type of difference, you know?”

In this paper we saw how discourses of cheapness, ease-of-use, and freedom from regulation propose that CRISPR is “universally accessible” but how in practice sharp lay/expert boundaries persist, and overlapping accesses to knowledge networks, funding, and infrastructure mediate the difference between access to a tool and the capacity to use it. We saw agricultural R&D underway at a powerhouse of CRISPR innovation, and scientists whose clonal hybrids seeds could free smallholders from corporate control – but could be hamstrung by lock-ins of IP, biotechnology, and public-private institutional ties. We saw openings in fora that invite lesser-heard voices into public discussion about the risks and opportunities of CRISPR technology. We also witnessed contradictions in being invited but tokenized, or asked to affirm a democracy foreign to one’s own understanding of that term. Moving beyond invited spaces to created spaces, we saw possibilities – like Red-TECLA – to engage in deep democratic processes, cognizant of social movements’ warnings that “you don’t need a big participatory technology assessment process to tell you this thing is not scratching where it itches.”

Can we begin with *that* conversation? Can we see CRISPR as an opportunity – not to democratize this specific tool, but to democratize all the social processes through which technologies are imagined, designed, and disseminated, struggled over and contested, embraced and resisted in the messy space of real-world use? Frances Moore Lappé, author of the 1971 best-seller, *Diet for a Small Planet*, recently put it like this: “Democracy stands for a set of three conditions that are necessary to bring forth the best in our nature and keep the worst in check. It means the continuous and wide dispersion of economic and political power; it means transparency; and it means cultivating a culture of mutual accountability” (Marchese, 2019). If science and political economy now coproduce conditions closed to such democratization, can we take CRISPR as an impetus for intervention – a chance to claim not just the right to participate effectively in a given space, but as the right to define and shape that space?

Data Accessibility Statements

Interview scripts are available as Supplementary Materials, SM2 and SM3. Documentary materials are all available at references cited in the bibliography. No further datasets were generated for this research.

Notes

- ¹ CRISPR was awarded “Breakthrough of the Year” by *Science* journal in 2015. In 2012 and 2013, it was runner-up (Travis, 2015). This recognition is just a small slice

of the prizes, grants, journal articles, citations, and other metrics that attest to its legitimation in the scientific arena.

- ² These scientists were selected according to noteworthy research and publications at the intersection of genetic engineering and one or more of the following areas: crop genetic diversity, social-ecological resilience, transitions to sustainability, indigenous and traditional knowledge, STS/political ecology, agroecology, ethics and bioethics, democratizing science and governance.
- ³ First- and second-generation gene editing technologies refers to genome editing platforms that pre-dated CRISPR, including transcription activator-like effector nucleases (TALEN), Zinc Finger Nucleases (ZFN), and meganucleases. While these techniques enabled targeted DNA editing, unlike CRISPR-Cas, they required researchers to design a new nuclease for each TALEN or ZFN study. With CRISPR-Cas systems, only the guide RNA sequence needs to be changed. Differences among these platforms also include target specificity, with the only theoretical requirement of the *S. pyogenes* CRISPR-Cas9 system being the presence of a “PAM” motif downstream of the target sequence (Bortesi and Fischer, 2015). As these differences translate into time- and cost-savings, the CRISPR-Cas systems – which include CRISPR-Cas9, but also CRISPR-Cpf1, CRISPR-Cas13, and a newer generation of “base editors” – have rapidly emerged as the favored platform among most scientists in the gene editing field.
- ⁴ Addgene operates under the terms of the Uniform Biological Material Transfer Agreement (UBMTA), developed in 1995 by the US National Institutes of Health to simplify transfers of biological materials to universities and public research institutions.
- ⁵ The company DowDuPont formed in 2017, merging Dow Chemical company with DuPont, a specialty chemical and legacy agricultural seed business. In early 2019, DowDuPont announced plans to break up into three separate companies (Root, 2019). Dow is now dedicated to commodity chemical production, DuPont to specialty chemical production, and Corteva to agricultural chemicals, seeds, and traits – including those developed using its significant portfolio of CRISPR-Cas9 IP (see Box 1).
- ⁶ Editing human germline cells – eggs, sperm and embryonic cells – results in heritable changes passed on to children and future generations. For that reason, it is considered particularly controversial and is formally prohibited in more than 40 countries (Center for Genetics and Society, 2019; see also special issue in *The CRISPR Journal*, 2019).
- ⁷ The IGI receives funding from philanthropic gifts, grants, and industry sponsorship. Named backers include: Li Ka Shing Foundation, DARPA (Defense Advanced Research Projects Agency), The Shurl and Kay Curci Foundation, MARS, John Templeton Foundation, Open Philanthropy Project, The Heritage Medical Research Institute, Biogemma, Burroughs Wellcome Fund. Many philanthropic gifts – including the main donation that enabled the IGI to become an institute – are also given anonymously.
- ⁸ BERGIT’s purview is not limited to human applications but its monthly meetings have tended to focus more on ethics of human genetic enhancement and therapies as opposed to agricultural questions. Out of approximately 10 monthly meetings to date, one meeting in February 2018 has specifically centered on agriculture.
- ⁹ There is debate about the extent to which hybrid seeds actually yielded more than open-pollinated varieties. Kloppenburg (2004) estimates that yield improvements from hybrid breeding were fairly marginal – about 10% at best. It was instead a tour de force of politics, and heavy funding, that garnered even these minimal yields.
- ¹⁰ Sexual reproduction in rice involves two basic processes. The first is meiosis, which divides the DNA into separate egg cells and sperm cells, reducing the number of chromosomes by half. The second is fertilization, which results in new genetic combinations by bringing egg cell and sperm cell together. Once fertilized, the egg begins to grow into an embryo, eventually forming a whole seed.
- ¹¹ See Carlson and Chappell (2015) for a more detailed discussion of synergies and differences between “food sovereignty,” “agrarian citizenship,” and “food democracy.” The last has been particularly spearheaded by North American food movements and may or may not share all elements of “deep democratization” as promoted by decolonial and sovereignty discourses and movements.
- ¹² The exemption will apply to biotech traits that, according to APHIS, do not pose a plant pest risk because they fall under one of the following categories: (1) the genetic modification is a deletion of any size; (2) the genetic modification is a single base pair substitution; (3) the genetic modification is solely introducing nucleic acid sequences from within the plant’s natural gene pool or from editing of nucleic acid sequences in a plant to correspond to a sequence known to occur in that plant’s natural gene pool; or (4) the plant is an offspring of a GE plant that does not retain the genetic modification in the parent. These exemptions reflect the Secretary of Agriculture’s March 28, 2018, statement that USDA does not plan to regulate plants that could otherwise have been developed through traditional breeding techniques.
- ¹³ Regulation of genetically engineered organisms in the US falls under a “Coordinated Framework for Regulation of Biotechnology” established in the mid-1980s between three agencies: the US Department of Agriculture (USDA), the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA). The USDA’s Animal Plant Inspection services has jurisdiction over the importation, interstate movement, or release into the environment of plants, including food, fuel, fiber, and fodder crops, while the FDA has oversight in animal products, drugs, and biological products. The EPA regulates plants with a built-in

pesticide, such as Bt. While this paper focuses on the USDA/APHIS, I note that in early 2017, the FDA issued draft guidance indicating that animals intentionally altered by gene editing would be regulated just like prior genetically modified animals have been – as containing veterinary drugs. In written responses to public questions, the FDA clarified that gene-edited animals aren't considered drugs in themselves but that they contain new animal drugs. The EPA has not developed new guidelines for gene editing, but if CRISPR crops are developed that produce pesticide, they would almost certainly trigger regulation.

¹⁴ The USDA, EPA, and FDA have long claimed reliance on “product based” standards, in contrast to the EU model which considers all organisms created using processes of genetic engineering to be regulated articles. Yet in practice, the *process* of genetic engineering has always served as the upstream trigger to capture products for pre-market review. Ironically, notes Kuzma (2016), the same developers who once claimed that ‘process’ does not matter for regulatory purposes are now arguing that gene editing merits looser regulatory scrutiny because the gene editing process is supposedly more precise than first-generation genetic engineering and smaller mutations are made.

¹⁵ The Latin American Coordination of Rural Organizations (CLOC-Vía Campesina) represents peasants, workers, indigenous communities, and Afro-descendant movements throughout Latin America. It comprises 84 organizations in 18 countries in Latin America and the Caribbean.

Supplemental files

The supplemental files for this article can be found as follows:

- **Text S1.** Who owns CRISPR IP? DOI: <https://doi.org/10.1525/elementa.405.s1>
- **Text S2.** Interview script A_CRISPR researchers. DOI: <https://doi.org/10.1525/elementa.405.s2>
- **Text S3.** Interview script B_SFS researchers and movements. DOI: <https://doi.org/10.1525/elementa.405.s3>

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Competing interests

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References

- 7 CFR 340.4.** 2008. Code of Federal Regulations: Permits for the introduction of a regulated article, Animal and Plant Health Inspection Service, US Department of Agriculture, Jan 1. [accessed 2019 Sep 28]. <https://www.govinfo.gov/content/pkg/CFR-2008-title7-vol5/xml/CFR-2008-title7-vol5-sec340-4.xml>.
- Aasen, M and Vatn, A.** 2013. Deliberation on GMOs: A study of how a citizens' jury affects the citizens' attitudes. *Environmental Values*. **22**(4): 461–481. DOI: <https://doi.org/10.3197/096327113X13690717320702>
- Agrawal, A.** 1995. Dismantling the divide between indigenous and Scientific Knowledge. *Development and Change* **26**(3): 413–439. DOI: <https://doi.org/10.1111/j.1467-7660.1995.tb00560.x>
- Allen and Overy.** 2017. CRISPR agriculture licensing landscape. Allen and Overy, LLP. [accessed 2019 Sep 27]. <http://www.allenoverly.com/SiteCollectionDocuments/Agriculture.pdf>.
- Anderson, CR, Maughan, C and Pimbert, MP.** 2018. Transformative agroecology learning in Europe: building consciousness, skills and collective capacity for food sovereignty, Nov 12. *Agriculture and Human Values*. [accessed 2018 Nov 18]. DOI: <https://doi.org/10.1007/s10460-018-9894-0>
- Arora, S, van Dyck, B, Argumedo, A and Wakeford, T.** 2019. Choreographed Consensus: The stifling of dissent at CRISPRcon 2019. STEPS Centre, Jun 28. [accessed 2020 Feb 4]. <https://steps-centre.org/blog/choreographed-consensus-the-stifling-of-dissent-at-crisprcon-2019/>.
- Bala, A and Joseph, GG.** 2007. Indigenous knowledge and western science: the possibility of dialogue. *Race & Class* **49**(1): 39–61. DOI: <https://doi.org/10.1177/0306396807080067>
- Baranski, M.** 2015. The wide adaptation of Green Revolution wheat [PhD Thesis]. Tempe, Arizona: Arizona State University. [accessed 2019 Sep 27]. https://repository.asu.edu/attachments/150706/content/Baranski_asu_0010E_15017.pdf.
- Barrangou, R.** 2018. The democratization of CRISPR. *The CRISPR Journal*, June 1. [accessed 2019 Jan 16]. <https://www.liebertpub.com/doi/abs/10.1089/crispr.2018.29019.rba>.
- Barrangou, R, Fremaux, C, Deveau, H, Richards, M, Boyaval, P, Moineau, S, Romero, DA and Horvath, P.** 2007. CRISPR provides acquired resistance against viruses in prokaryotes. *Science* **315** (5819): 1709–1712. DOI: <https://doi.org/10.1126/science.1138140>
- Beck, U.** 1992. *Risk society: Towards a new modernity*. Thousand Oaks, CA: Sage Publications.
- Berg, P.** 2008. Asilomar 1975: DNA modification secured. *Nature* **455**(7211): 290–291. DOI: <https://doi.org/10.1038/455290a>

- Bernstein, H.** 2010. *Class dynamics of agrarian change*. Halifax, NS; Sterling, VA: Fernwood Pub.; Kumarian Press (Agrarian change and peasant studies series).
- Boettiger, S** and **Bennett, AB.** 2006. Bayh-Dole: if we knew then what we know now. *Nat Biotechnol.* **24**(3): 320–323. DOI: <https://doi.org/10.1038/nbt0306-320>
- Bomgardner, MM.** 2017. CRISPR: A new toolbox for better crops. *Chemical & Engineering News.* **95**(24). [accessed 2019 Sep 26]. <https://cen.acs.org/articles/95/i24/CRISPR-new-toolbox-better-crops.html>. DOI: <https://doi.org/10.1021/cen-09524-cover1>
- Borrelli, VMG, Brambilla, V, Rogowsky, P, Marocco, A** and **Lanubile, A.** 2018. The enhancement of plant disease resistance using CRISPR/Cas9 technology. *Frontiers in Plant Sciences.* **9**. [accessed 2019 Apr 28]. DOI: <https://doi.org/10.3389/fpls.2018.01245>
- Bortesi, L** and **Fischer, R.** 2015. The CRISPR/Cas9 system for plant genome editing and beyond. *Biotechnology Advances* **33**(1): 41–52. DOI: <https://doi.org/10.1016/j.biotechadv.2014.12.006>
- Braun, B.** 1997. Buried epistemologies: the politics of nature in (post) colonial British Columbia. *Annals of the Association of American Geographers* **87**(1): 3–31. DOI: <https://doi.org/10.1111/0004-5608.00039>
- Brodwin, E.** 2019. We'll be eating the first Crispr'd foods within 5 years, according to a geneticist who helped invent the blockbuster gene-editing tool. *Business Insider.* [accessed 2019 Sep 26]. <https://www.businessinsider.com/first-crispr-food-5-years-berkeley-scientist-inventor-2019-4>.
- Brooks, C, Nekrasov, V, Lippman, ZB** and **Van Eck, J.** 2014. Efficient gene editing in tomato in the first generation using the Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-Associated9 system. *Plant Physiology* **166**(3): 1292–1297. DOI: <https://doi.org/10.1104/pp.114.247577>
- Brown, P.** 2013. Maya mother seeds in resistance of highland Chiapas in defense of native corn. In: Nazarea, VD, Rhoades, RE and Andrews-Swann, J (eds.), *Seeds of resistance, seeds of hope: place and agency in the conservation of biodiversity*, 151–176. Tucson: University of Arizona Press.
- Busch, L** and **Lacy, WB.** 1983. *Science, agriculture, and the politics of research*. New York, NY: Routledge.
- Bush, V.** 1945. *Science: the endless frontier*. New York: American Council of Learned Societies.
- Buttel, FH.** 2005. Ever since Hightower: The politics of agricultural research activism in the molecular age. *Agriculture and Human Values* **22**(3): 275–283. DOI: <https://doi.org/10.1007/s10460-005-6043-3>
- Buttel, FH** and **Busch, L.** 1988. The public agricultural research system at the crossroads. *Agricultural History* **62**(2): 303–324.
- Callon, M, Lascoumes, P** and **Barthe, Y.** 2009. *Acting in an uncertain world: an essay on technical democracy*. Cambridge, Mass: MIT Press.
- Cameron, D.** 2017. DuPont Pioneer and Broad Institute join forces to enable democratic CRISPR licensing in agriculture. Broad Institute, Oct 18. [accessed 2019 Oct 1]. <https://www.broadinstitute.org/news/duPont-pioneer-and-broad-institute-join-forces-enable-democratic-crispr-licensing-agriculture>.
- Caribou Biosciences.** 2015. Caribou Biosciences and DuPont announce strategic alliance, Caribou Biosciences, Inc. News, Oct 8. [accessed 2019 Sep 28]. <https://cariboubio.com/in-the-news/press-releases/caribou-biosciences-and-dupont-announce-strategic-alliance>.
- Carlson, J** and **Chappell, MJ.** 2015. Deepening food democracy: The tools to create a sustainable, food secure and food sovereign future are already here—deep democratic approaches can show us how. Institute for Agriculture and Trade Policy, January [accessed 2019 Oct 1]. <http://safsc.org.za/wp-content/uploads/2015/09/DEEPENING-FOOD-DEMOCRACY.pdf>.
- Carolan, MS.** 2008. The bright- and blind-spots of science: Why objective knowledge is not enough to resolve environmental controversies. *Critical Sociology* **34**(5): 725–740. DOI: <https://doi.org/10.1177/0896920508093365>
- Center for Genetics and Society.** 2019. About human germline gene editing. [accessed 2019 Dec 17]. <https://www.geneticsandsociety.org/internal-content/about-human-germline-gene-editing>.
- Chesnut, J.** 2017 Jun 16. Democratizing genome editing. *Lab Manager.* [accessed 2019 Sep 26]. <https://www.labmanager.com/laboratory-technology/2017/06/democratizing-genome-editing>.
- Cohen, J.** 2019. China's CRISPR revolution. *Science* **365**(6452): 420–421. DOI: <https://doi.org/10.1126/science.365.6452.420>
- Cong, L, Ran, FA, Cox, D, Lin, S, Barretto, R, Habib, N, Hsu, PD, Wu, X, Jiang, W, Marraffini, LA** and **Zhang, F.** 2013. Multiplex genome engineering using CRISPR/Cas systems. *Science* **339**(6121): 819–823. DOI: <https://doi.org/10.1126/science.1231143>
- Contreras, JL** and **Sherkow, JS.** 2017. CRISPR, surrogate licensing, and scientific discovery. *Science* **355**(6326): 698–700. DOI: <https://doi.org/10.1126/science.aal4222>
- Conway, G.** 1998. *The doubly green revolution: food for all in the twenty-first century*. Ithaca, N.Y: Comstock Pub. Associates.
- Corteva.** 2019. Corteva™ separates from DowDuPont to form leading pure-play agriculture company. Corteva Agriscience Press Release, Jun 3. [accessed 2019 Dec 16]. <https://www.corteva.com/resources/media-center/corteva-separates-from-dowdupont-to-form-leading-independent-global-pure-play-agriculture-company.html>.
- CRISPRcon.** 2019. Reflections from CRISPRcon 2019 [Video]. (Keystone Policy Center). [accessed 2019 Sep 28]. <https://www.youtube.com/watch?v=NRjUriwnzKo&t=1s>.

- Cullather, N.** 2010. *The hungry world: America's Cold War battle against poverty in Asia*. Cambridge, Mass.: Harvard Univ. Press. DOI: <https://doi.org/10.2307/j.ctvjnr65>
- Curry, J** and **Kenney, M.** 1990. Land-grant university-industry relationships in biotechnology: A comparison with the non-land-grant research universities. *Rural Sociology* 55(1): 44–57. DOI: <https://doi.org/10.1111/j.1549-0831.1990.tb00672.x>
- Dinh, A.** 2014. Dow SISCA awards \$ 10k to critical agricultural research for developing world. The Center for Responsible Business (CRB). [accessed 2019 Sep 26]. <https://redefiningbusiness.org/dow-sisca-awards-10k-to-critical-agricultural-research-for-developing-world/>.
- Dumont, AM, Vanloqueren, G, Stassart, PM** and **Baret, PV.** 2016. Clarifying the socioeconomic dimensions of agroecology: between principles and practices. *Agroecology and Sustainable Food Systems* 40(1): 24–47. DOI: <https://doi.org/10.1080/21683565.2015.1089967>
- Dussel, ED.** 1985. *Philosophy of liberation*. Martinez, A, Morkovsky, C, translators. New York: Orbis Books.
- Dussel, ED.** 2013. *Ethics of liberation in the age of globalization and exclusion*. Vallega, AA (ed.). Durham: Duke University Press (Latin America Otherwise: languages, empires, nations).
- Duvick, DN.** 2001. Biotechnology in the 1930s: the development of hybrid maize. *Nature Reviews Genetics* 2(1): 69–74. DOI: <https://doi.org/10.1038/35047587>
- Edelman, M.** 2014. Food sovereignty: forgotten genealogies and future regulatory challenges. *The Journal of Peasant Studies*. 41(6): 959–978. DOI: <https://doi.org/10.1080/03066150.2013.876998>
- Egelie, KJ, Graff, GD, Strand, SP** and **Johansen, B.** 2016. The emerging patent landscape of CRISPR–Cas gene editing technology. *Nature Biotechnology* 34(10): 1025–1031. DOI: <https://doi.org/10.1038/nbt.3692>
- Eisenberg, RS.** 1996. Public research and private development: Patents and technology transfer in government–sponsored research. *Virginia Law Review* 82: 1663. DOI: <https://doi.org/10.2307/1073686>
- Epstein, S.** 1995. The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials. *Science, Technology, & Human Values* 20(4): 408–437. DOI: <https://doi.org/10.1177/016224399502000402>
- Evenson, RE** and **Gollin, D.** 2003. Assessing the impact of the Green Revolution, 1960 to 2000. *Science* 300(5620): 758–762. DOI: <https://doi.org/10.1126/science.1078710>
- Fairbairn, M.** 2010. Framing resistance: International food regimes & the roots of food sovereignty. In: Wittman, H, Desmarais, AA and Wiebe, N (eds.), *Food sovereignty: reconnecting food, nature et community*, 15–32. Oakland: Food First Books.
- Felicien, A, Schiavoni, CM, Ochoa, E, Saturno, S, Omaña, E, Requena, A** and **Camacaro, W.** 2018. Exploring the 'grey areas' of state-society interaction in food sovereignty construction: the battle for Venezuela's seed law. *The Journal of Peasant Studies*, 1–26. DOI: <https://doi.org/10.1080/03066150.2018.1525363>
- Fitting, EM.** 2011. *The struggle for maize: campesinos, workers, and transgenic corn in the Mexican countryside*. Durham, NC: Duke University Press. DOI: <https://doi.org/10.1215/9780822393863>
- Fraser, N.** 2017. The end of progressive neoliberalism. *Dissent Magazine*, Jan 2. [accessed 2019 Dec 20]. https://www.dissentmagazine.org/online_articles/progressive-neoliberalism-reactionary-populism-nancy-fraser.
- Freire, P.** 1970. *Pedagogy of the oppressed*. Ramos MB, translator. New York: Bloomsbury Academic.
- Freire, P.** 2014. *Pedagogy of hope: reliving Pedagogy of the oppressed*. London; New York: Bloomsbury.
- Gaskell, G, Allum, N, Wagner, W, Kronberger, N, Torgersen, H, Hampel, J** and **Bardes, J.** 2004. GM foods and the misperception of risk perception. *Risk Analysis*. 24(1): 185–194. DOI: <https://doi.org/10.1111/j.0272-4332.2004.00421.x>
- Gaventa, J.** 2003. Towards participatory local governance: Assessing the transformative possibilities. Conference on Participation: From Tyranny to Transformation, Manchester, UK, February 27–28.
- Gaventa, J.** 2006. Finding the spaces for change: A power analysis. *Institute for Development Studies Bulletin* 37(6): 23–33. DOI: <https://doi.org/10.1111/j.1759-5436.2006.tb00320.x>
- Gaventa, J** and **Pettit, J.** 2011. Power pack: Understanding power for social change. [accessed 2019 Sep 27]. <https://www.powercube.net/wp-content/uploads/2011/04/powerpack-web-version-2011.pdf>.
- Glenna, LL, Lacy, WB, Welsh, R** and **Biscotti, D.** 2007. University administrators, agricultural biotechnology, and academic capitalism: Defining the public good to promote university–industry relationships. *The Sociological Quarterly* 48(1): 141–163. DOI: <https://doi.org/10.1111/j.1533-8525.2007.00074.x>
- Glover, D, Sumberg, J, Ton, G, Andersson, J** and **Badstue, L.** 2019. Rethinking technological change in smallholder agriculture. *Outlook Agric.* 48(3): 169–180. DOI: <https://doi.org/10.1177/0030727019864978>
- Goetz, AM** and **Gaventa, J.** 2001. Bringing citizen voice and client focus into service delivery. Institute of Development Studies (IDS) Working Paper #38, Brighton, England. [accessed 2019 Sep 27].
- Goldstein, JE, Paprocki, K** and **Osborne, T.** 2019. A manifesto for a progressive land-grant mission in an authoritarian populist era. *Annals of the American Association of Geographers* 109(2): 673–684. DOI: <https://doi.org/10.1080/24694452.2018.1539648>
- Gomez, MA.** 2019. Genome editing of the staple crop cassava to eliminate toxic cyanogen production. Plant Genome Engineering Symposium 2019, May 24. University of California, Berkeley. <https://pges.berkeley.edu/>.

- Gomez, MA, Lin, ZD, Moll, T, Chauhan, RD, Hayden, L, Renninger, K, Beyene, G, Taylor, NJ, Carrington, JC, Staskawicz, BJ and Bart, RS.** 2019. Simultaneous CRISPR/Cas9-mediated editing of cassava *eIF4E* isoforms *nCBP-1* and *nCBP-2* reduces cassava brown streak disease symptom severity and incidence. *Plant Biotechnology Journal* **17**(2): 421–434. DOI: <https://doi.org/10.1111/pbi.12987>
- Goodman, D, Sorj, B and Wilkinson, J.** 1987. *From farming to biotechnology: a theory of agro-industrial development*. Oxford; New York, N.Y: Basil Blackwell.
- GRAIN.** 2019. Biofortified crops or biodiversity? The fight for genuine solutions to malnutrition is on. *GRAIN*. [accessed 2019 Sep 26]. https://grain.org/system/articles/pdfs/000/006/246/original/Biofortified_Crops_EN_07.pdf?1559594700.
- GRAIN, LVC (La Vía Campesina).** 2015. Seed laws that criminalize farmers: resistance and fight back. [accessed 2015 Aug 4]. <http://viacampesina.org/en/images/stories/pdf/2015-Seed%20laws%20booklet%20EN.pdf>.
- Greely, HT.** 2015. Of science, CRISPR-Cas9, and Asilomar. Stanford Law School, Apr 4. [accessed 2019 Dec 14]. <https://law.stanford.edu/2015/04/04/of-science-crispr-cas9-and-asilomar/>.
- Hall, SS.** 2016. New gene-editing techniques could transform food crops – or die on the vine. *Scientific American*, March 1. [accessed 2019 October 1]. <https://www.scientificamerican.com/article/new-gene-editing-techniques-could-transform-food-crops-or-die-on-the-vine/>.
- Halpern, J, O'Hara, SE, Doxzen, KW, Witkowsky, LB and Owen, AL.** 2019. Societal and ethical impacts of germline genome editing: How can we secure human rights? *The CRISPR Journal* **2**(5): 293–298. DOI: <https://doi.org/10.1089/crispr.2019.0042>
- Haraway, D.** 1988. Situated knowledges: The science question in feminism and the privilege of partial perspective. *Feminist Studies* **14**(3): 575. DOI: <https://doi.org/10.2307/3178066>
- Harding, SG.** 1991. *Whose science? Whose knowledge? thinking from women's lives*. Ithaca, N.Y: Cornell University Press.
- Hazell, P, Poulton, C, Wiggins, S and Dorward, A.** 2010. The future of small farms: Trajectories and policy priorities. *World Development* **38** (10): 1349–1361. DOI: <https://doi.org/10.1016/j.worlddev.2009.06.012>
- HLPE (High Level Panel of Experts on Food Security and Nutrition).** 2019. Agroecological approaches and other innovations for sustainable agriculture and food systems that enhance food security and nutrition|HLPE Report 14. [accessed 2019 Dec 4] <http://www.fao.org/3/ca5602en/ca5602en.pdf>.
- Holling, CS.** 1973. Resilience and stability of ecological systems. *Annu Rev Ecol Syst.* **4**(1): 1–23. DOI: <https://doi.org/10.1146/annurev.es.04.110173.000245>
- Ickowitz, A, Powell, B, Rowland, D, Jones, A and Sunderland, T.** 2019. Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Global Food Security* **20**: 9–16. DOI: <https://doi.org/10.1016/j.gfs.2018.11.002>
- IGI (Innovative Genomics Institute).** 2017. New entrepreneurial fellows: Business-minded scientists with big ideas, Mar 21. [accessed 2019 Sep 28]. <https://innovativegenomics.org/news/entrepreneurial-fellows-announced/>.
- IGI (Innovative Genomics Institute).** 2018. New project to create disease-resistant cacao. Innovative Genomics Institute (IGI) News, January 2. [accessed 2019 Sep 26]. <https://innovativegenomics.org/news/new-project-to-create-disease-resistant-cacao/>.
- IGI (Innovative Genomics Institute).** 2019a. Plant Genomics and Transformation Facility. Innovative Genomics Institute (IGI). <https://innovativegenomics.org/pgtf/>.
- IGI (Innovative Genomics Institute).** 2019b. CRISPR (un)commons artist residency program launches, March 20. [accessed 2019 Sep 26]. <https://innovativegenomics.org/news/crispr-uncommons-artist-residency-program-launches/>.
- Iles, A and Montenegro de Wit, M.** 2015. Sovereignty at what scale? An inquiry into multiple dimensions of food sovereignty. *Globalizations* **12**(4): 481–497. DOI: <https://doi.org/10.1080/14747731.2014.957587>
- IPES-Food.** 2016. From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. [accessed 2017 Oct 19]. <http://www.ipes-food.org>.
- IPStudies.** 2018. Myths and realities on DuPont CRISPR assets – IPStudies, Feb. 16. [accessed 2019 Dec 15]. <https://www.ipstudies.ch/2018/02/myths-and-realities-on-dupont-crispr-assets/>.
- Isaac, G, Finn, S, Joe, JR, Hoover, E, Gone, JP, Lefthand-Begay, C and Hill, S.** 2018. Native American perspectives on health and traditional ecological knowledge. *Environ Health Perspect.* **126**(12): 125002. DOI: <https://doi.org/10.1289/EHP1944>
- Jaffe, G.** 2019. Trump administration proposes deregulatory shift on agricultural biotechnology, Center for Science in the Public Interest. [accessed 2019 Jun 23]. <https://cspinet.org/news/trump-administration-proposes-deregulatory-shift-agricultural-biotechnology-20190612>.
- Jasanoff, S.** 2005. *Designs on nature: science and democracy in Europe and the United States*. Princeton, NJ: Princeton Univ. Press. DOI: <https://doi.org/10.1515/9781400837311>
- Jasanoff, S.** 2017. Science and Democracy. In: *The Handbook of Science and Technology Studies*, 4th edition, Felt, U, Fouché, R, Miller, C and Smith-Doerr, L (eds), Ch. 9, 259–288. Cambridge, MA: MIT Press.
- Jasanoff, S, Hurlbut, JB and Saha, K.** 2015. CRISPR democracy: Gene editing and the need for inclusive deliberation. *Issues in Science and Technology.* **XXXII**(1).

- Jasanoff, S** and **Wynne, B.** 1998. Science and decision-making. In: *Human choice and climate change*, 1: 1–87. The societal framework. Ohio: Battelle Press. [accessed 2017 Sep 30].
- Jennings, BH.** 1988. *Foundations of international agricultural research: science and politics in Mexican agriculture*. Boulder: Westview Press (Westview special studies in agriculture science and policy).
- Jinek, M, Chylinski, K, Fonfara, I, Hauer, M, Doudna, JA** and **Charpentier, E.** 2012. A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. *Science* **337**(6096): 816–821. DOI: <https://doi.org/10.1126/science.1225829>
- Kerr, E.** 2019. Gene editing and science breakthroughs with AgBiome and CRISPR and DuPontDow's new spin off, Corteva, plans to grow quickly. *Tenor Agrochemical News*, June 9 [accessed 2019 Dec 16]. <https://www.tenorpr.com/2019/06/tenor-agrochemical-news-headlines-24-19-gene-editing-and-science-breakthroughs-with-agbiome-and-crispr-and-dupontdows-new-spin-off-corteva-plans-to-grow-quickly/>.
- Khanday, I, Skinner, D, Yang, B, Mercier, R** and **Sundaresan, V.** 2018. A male-expressed rice embryogenic trigger redirected for asexual propagation through seeds. *Nature* **565**: 91–95. [accessed 2018 Dec 19]. DOI: <https://doi.org/10.1038/s41586-018-0785-8>
- Khanday, I** and **Sundaresan, V.** 2019. Synthetic apomixis in a crop plant, Patent No. WO2019104346A1; File date: Nov 27, 2018. Issue date: May 31, 2019. [accessed 2019 Jun 26]. <https://patents.google.com/patent/WO2019104346A1>.
- Kinchy, AJ.** 2012. *Seeds, science, and struggle: the global politics of transgenic crops*. Cambridge, MA: The MIT Press. DOI: <https://doi.org/10.7551/mitpress/9099.001.0001>
- Klein, N.** 2014. *This changes everything: capitalism vs. the climate*. New York: Simon & Schuster.
- Kleinman, DL.** 2000. Democratizations of science and technology. In: Kleinman, DL (ed.). *Science, technology, and democracy*, 125–165. Albany: State University of New York Press.
- Kloppenborg, JR.** 2004. *First the seed: the political economy of plant biotechnology*, 1492–2000. 2nd ed. Madison, Wis: University of Wisconsin Press (Science and technology in society).
- Kuzma, J.** 2016. Policy: Reboot the debate on genetic engineering. *Nature* **531**(7593): 165–167. DOI: <https://doi.org/10.1038/531165a>
- Kuzma, J.** 2019. Biotechnology oversight gets an early make-over by Trump's White House and USDA: Part 2 – The USDA-APHIS Rule. Genetic Engineering and Society Center, NC State, Jul 2. [accessed 2019 Jul 31]. <https://research.ncsu.edu/ges/2019/07/ag-biotech-oversight-makeover-part-2-usda-aphis-rule/>.
- LaManna, CM** and **Barrangou, R.** 2018. Enabling the rise of a CRISPR world. *The CRISPR Journal* **1**(3): 205–208. DOI: <https://doi.org/10.1089/crispr.2018.0022>
- Lapegna, P.** 2016. *Soybeans and power: genetically modified crops, environmental politics, and social movements in Argentina*. New York: Oxford University Press (Global and comparative ethnography). DOI: <https://doi.org/10.1093/acprof:oso/9780190215132.001.0001>
- Ledford, H.** 2015. CRISPR, the disruptor. *Nature News* **522**(7554): 20. DOI: <https://doi.org/10.1038/522020a>
- Lefebvre, H.** 1991. *The production of space*. First Edition. Nicholson-Smith D, translator. Malden, Mass.: Blackwell.
- Lemmon, ZH, Reem, NT, Dalrymple, J, Soyk, S, Swartwood, KE, Rodriguez-Leal, D, Eck, JV** and **Lippman, ZB.** 2018. Rapid improvement of domestication traits in an orphan crop by genome editing. *Nature Plants* **4**(10): 766–770. DOI: <https://doi.org/10.1038/s41477-018-0259-x>
- Levidow, L.** 1998. Democratizing technology—or technologizing democracy? Regulating agricultural biotechnology in Europe. *Technology in Society* **20**(2): 211–226. DOI: [https://doi.org/10.1016/S0160-791X\(98\)00003-7](https://doi.org/10.1016/S0160-791X(98)00003-7)
- Levidow, L** and **Carr, S.** 1997. How biotechnology regulation sets a risk/ethics boundary. *Agriculture and Human Values* **14**(1): 29–43. DOI: <https://doi.org/10.1023/A:1007394812312>
- Levidow, L** and **Carr, S.** 2010. GM food on trial: testing European democracy. New York: Routledge (Genetics and society). DOI: <https://doi.org/10.4324/9780203866696>
- Luby, CH, Kloppenburg, J, Michaels, TE** and **Goldman, IL.** 2015. Enhancing freedom to operate for plant breeders and farmers through open source plant breeding. *Crop Science* **55** (6): 2481–2488. DOI: <https://doi.org/10.2135/cropsci2014.10.0708>
- LVC (La Vía Campesina).** 2011. Bali Seed Declaration - Peasant seeds: Dignity, culture and life. Farmers in resistance to defend their right to peasant seeds. Via Campesina English. [accessed 2017 Oct 20]. <https://viacampesina.org/en/peasant-seeds-dignity-culture-and-life-farmers-in-resistance-to-defend-their-right-to-peasant-seeds/>.
- Macnaghten, P** and **Habets, M.** In Review. Breaking the impasse: Towards a forward-looking governance framework for gene editing with plants. *Plants, People, Planet*.
- Marchese, D.** 2019. She changed the way we eat. She wants to fix our democracy, too. *The New York Times*, Dec 16. [accessed 2019 Dec 20]. <https://www.nytimes.com/interactive/2019/12/16/magazine/frances-moore-lappe.html>.
- Mazoyer, M** and **Roudart, L.** 2006. *A history of world agriculture: from the neolithic age to the current crisis*. New York: Monthly Review Press. DOI: <https://doi.org/10.4324/9781849773812>
- Meek, D.** 2018 Feb 26. Cracks in the wall of capitalism: The Zapatistas and the struggle to decolonize science. *Toward Freedom*. [accessed 2019 Sep 28].

- <https://towardfreedom.org/archives/americas/cracks-in-the-wall-of-capitalism-the-zapatistas-and-the-struggle-to-decolonize-science/>.
- Méndez, VE, Bacon, CM, Cohen, R and Gliessman, SR**, eds. 2016. *Agroecology: a transdisciplinary, participatory and action-oriented approach*. Boca Raton: CRC Press/Taylor & Francis Group (Advances in agroecology). DOI: <https://doi.org/10.1201/b19500>
- Mignolo, WD and Escobar, A**, eds. 2013. *Globalization and the decolonial option*. London: Routledge. DOI: <https://doi.org/10.4324/9781315868448>
- Mitchell, T**. 2002. *Rule of experts: Egypt, techno-politics, modernity*. Berkeley, CA: University of California Press.
- Murphy, M**. 2006. *Sick building syndrome and the problem of uncertainty: environmental politics, technoscience, and women workers*. Durham, NC: Duke University Press. <https://doi.org/10.1215/9780822387831>
- NASEM (National Academies of Sciences, Engineering, and Medicine)**. 2019. Science breakthroughs to advance food and agricultural research by 2030. Washington, DC: The National Academies Press. DOI: <https://doi.org/10.17226/25059>
- Niiler, E**. 2018. How Crispr could transform our food supply. *National Geographic*, August 10. [accessed 2019 Mar 27]. <https://www.national-geographic.com/environment/future-of-food/food-technology-gene-editing/>.
- Nyéleni**. 2007. Nyéleni Forum for Food Sovereignty, *Sélingué, Mali*, 23–27, February. Selingue, Mali: Forum for Food Sovereignty.
- Olsson, TC**. 2017. *Agrarian crossings: reformers and the remaking of the US and Mexican countryside*. Princeton: Princeton University Press (America in the world). DOI: <https://doi.org/10.2307/j.ctt1vwmgrrq>
- Parthasarathy, S and Stilgoe, J**. 2019. The Received Wisdom podcast, Episode 3: Considering ethical responsibility in science and technology ft. *Nicholas Carr*, December 9. [accessed 2019 Dec 19] <http://shobitap.org/the-received-wisdom>.
- Patel, R**. 2009. Food sovereignty. *The Journal of Peasant Studies*. **36**(3): 663–706. DOI: <https://doi.org/10.1080/03066150903143079>
- Patel, R**. 2013. The long Green Revolution. *Journal of Peasant Studies* **40**(1): 1–63. DOI: <https://doi.org/10.1080/03066150.2012.719224>
- Pechlaner, G and Otero, G**. 2008. The third food regime: Neoliberal globalism and agricultural biotechnology in North America. *Sociologia Ruralis* **48**(4): 351–371. DOI: <https://doi.org/10.1111/j.1467-9523.2008.00469.x>
- PGES**. 2019. Plant Genomics Engineering Symposium 2019. University of California, Berkeley. [accessed 2019 Sep 26]. <https://pges.berkeley.edu/>.
- Philbrick, M and Barandiaran, J**. 2009. The national citizens' technology forum: Lessons for the future. *Sci and Pub Pol* **36**(5): 335–347. DOI: <https://doi.org/10.3152/030234209X442052>
- Pimbert, M, Wakeford, T and Satheesh, PV**. 2001. Citizens' Juries on GMOs and Farming Futures in India. *LEISA Magazine* **17**: 27–30.
- PKEC (People's Knowledge Editorial Collective, Eds)**. 2017. Everyday experts: How people's knowledge can transform the food system. Reclaiming Diversity and Citizenship Series. Coventry: Coventry University. [accessed 2019 Dec 20]. www.coventry.ac.uk/everyday-experts.
- Plantum**. 2019. Plantum-visie genome editing. Plantum. [accessed 2019 Dec 21] <https://assets.plantum.nl/p/229377//files/Plantum-visie%20genome%20editing.pdf>.
- Powell, M and Lee Kleinman, D**. 2008. Building citizen capacities for participation in nanotechnology decision-making: the democratic virtues of the consensus conference model. *Public Underst Sci*. **17**(3): 329–348. DOI: <https://doi.org/10.1177/0963662506068000>
- Pretty, J, Benton, TG, Bharucha, ZP, Dicks, LV, Flora, CB, Godfray, HCJ, Goulson, D, Hartley, S, Lampkin, N, Morris, C and Pierzynski, G**. 2018. Global assessment of agricultural system redesign for sustainable intensification. *Nat Sustain*. **1**(8): 441–446. DOI: <https://doi.org/10.1038/s41893-018-0114-0>
- Pskowski, M**. 2019. Indigenous maize: Who owns the rights to Mexico's 'wonder' plant? *Yale E360*, July 16. [accessed 2019 Sep 26]. <https://e360.yale.edu/features/indigenous-maize-who-owns-the-rights-to-mexicos-wonder-plant>.
- Regalado, A**. 2015. Everything you need to know about CRISPR gene editing's monster year. *MIT Technology Review*, Dec 1. [accessed 2019 Sep 26]. <https://www.technologyreview.com/s/543941/everything-you-need-to-know-about-crispr-gene-editings-monster-year/>.
- Rivera Cusicanqui, S**. 2010. *Violencias (re) encubiertas en Bolivia*. La Paz, Bolivia: Mirada Salvaje.
- Root, A**. 2019. DowDuPont is splitting into 3 companies. Here's everything you need to know. *Barron's*, April 29. [accessed 2019 Dec 16]. <https://www.barrons.com/articles/dowdupont-spinoff-dow-dupont-corteva-51556552428>.
- Royal Society**. 2009. Reaping the benefits: Science and the sustainable intensification of global agriculture, Royal Society, UK, Oct. https://royalsociety.org/-/media/Royal_Society_Content/policy/publications/2009/4294967719.pdf.
- Saha, M**. 2013. Food for soil, food for people: Research on food crops, fertilizers, and the making of "modern" Indian agriculture. *Technology and Culture* **54**(2): 289–316. DOI: <https://doi.org/10.1353/tech.2013.0059>
- Sarewitz, D**. 2000. Human well-being and federal science—what's the connection? In: Kleinman, DL (ed.), *Science, technology, and democracy*. Albany: State University of New York Press. (SUNY series in science, technology, and society).
- Schultink, A, Qi, T, Lee, A, Steinbrenner, AD and Staskawicz, B**. 2017. Roq1 mediates recognition

- of the *Xanthomonas* and *Pseudomonas* effector proteins XopQ and HopQ1. *The Plant Journal* **92**(5): 787–795. DOI: <https://doi.org/10.1111/tpj.13715>
- Schurman, R** and **Munro, WA**. 2003. Making biotech history: Social resistance to agricultural biotechnology and the future of the biotechnology industry. In: Schurman, R and Kelso, DD (eds.), *Engineering trouble: biotechnology and its discontents*, 111–129. Berkeley: University of California Press. DOI: <https://doi.org/10.1525/california/9780520237612.003.0005>
- Schurman, R** and **Munro, WA**. 2010. *Fighting for the future of food: activists versus agribusiness in the struggle over biotechnology*. Minneapolis, MN: University of Minnesota Press.
- Sclove, R**. 1995. *Democracy and technology*. New York: The Guilford Press.
- Scott, C**. 2018. CRISPR: A democratizing technology calls for democratic dialogue. Baylor College of Medicine Blog Network, April 27. [accessed 2019 Sep 26]. <https://blogs.bcm.edu/2018/04/27/crispr-a-democratizing-technology-calls-for-democratic-dialogue/>.
- Searchinger, T, Waite, R, Hanson, C, Ranganathan, J, Dumas, P, Matthews, E** and **Klirs, C**. 2019. Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. Final report, July. World Resources Institute, 1–564.
- Servando, K**. 2019. China's mutant pigs could help save nation from pork apocalypse. *Bloomberg*, Dec 3. [accessed 2019 Dec 20]. <https://www.bloomberg.com/news/features/2019-12-03/china-and-the-u-s-are-racing-to-create-a-super-pig>.
- Shan, Q, Wang, Y, Li, J, Zhang, Y, Chen, K, Liang, Z, Zhang, K, Liu, J, Xi, JJ, Qiu, JL** and **Gao, C**. 2013. Targeted genome modification of crop plants using a CRISPR-Cas system. *Nature Biotechnology* **31**(8): 686–688. DOI: <https://doi.org/10.1038/nbt.2650>
- Shao, E** and **Pershad, Y**. 2019. CRISPR co-inventor Jennifer Doudna talks ethics and biological frontiers. Stanford|McCoy Family Center for Ethics in Society. [accessed 2019 Jul 8]. <https://ethicsinsociety.stanford.edu/buzz-blog/crispr-co-inventor-jennifer-doudna-talks-ethics-and-biological-frontiers>.
- Shapin, S** and **Schaffer, S**. 1985. *Leviathan and the air-pump: Hobbes, Boyle, and the experimental life*. Princeton, NJ: Princeton University Press (Princeton classics).
- Shattuck, A**. 2019. Contesting harm: Epistemic emergence and the politics of the imperceptible. Skagen School III Workshop, Belfast, Maine, July 25-Aug 1.
- Sherkow, J**. 2015. The CRISPR patent interference showdown is on: How did we get here and what comes next? Stanford Law School Blog, Dec 29. [accessed 2019 Mar 21]. <https://law.stanford.edu/2015/12/29/the-crispr-patent-interference-showdown-is-on-how-did-we-get-here-and-what-comes-next/>.
- Siegel, BR**. 2018. *Hungry nation: Food, famine, and the making of modern India*. 1st ed. Cambridge University Press. [accessed 2019 Sep 27]. <https://www.cambridge.org/core/product/identifier/9781108605397/type/book>. DOI: <https://doi.org/10.1017/9781108605397>
- SISCA**. 2019. Dow Corporate. Dow Sustainability Innovation Student Challenge Award (SISCA). [accessed 2019 Sep 26]. <https://corporate.dow.com/en-us/science-and-sustainability/working-together/universities/sisca>.
- Sternberg, SH**. 2019. The CRISPR revolution: What you need to know. Columbia University Irving Medical Center, Mar 20. [accessed 2019 Sep 26]. <https://www.cuimc.columbia.edu/news/crispr-revolution-what-you-need-know>.
- Stilgoe, J, Owen, R** and **Macnaghten, P**. 2013. Developing a framework for responsible innovation. *Research Policy* **42**(9): 1568–1580. DOI: <https://doi.org/10.1016/j.respol.2013.05.008>
- Stone, GD**. 2014. Bioinsecurity and vulnerability. In: Nancy, NC and Leslie, AS (eds.), *Biosecurity in the Age of Genetic Engineering*, 71–86. Santa Fe, New Mexico: School for Advanced Research Press.
- Stone, GD**. 2019. Commentary: New histories of the Indian Green Revolution. *The Geographical Journal* **185**(2): 243–250. DOI: <https://doi.org/10.1111/geoj.12297>
- Stone, GD** and **Flachs, A**. 2014. The problem with the farmer's voice. *Agriculture and Human Values* **31**(4): 649–653. DOI: <https://doi.org/10.1007/s10460-014-9535-1>
- Subramanian, K**. 2015. Revisiting the Green Revolution: Irrigation and food production in twentieth-century India [PhD Thesis]. King's College London.
- Suppan, S**. 2019. USDA to biotech: Call your own compliance, Institute for Agriculture and Trade Policy, July 30. [accessed 2019 Jul 31]. <https://www.iatp.org/blog/201907/usda-biotech-call-your-own-compliance>.
- Taylor, AP**. 2019. Companies Use CRISPR to improve crops. *The Scientist Magazine*, Feb 1. [accessed 2019 May 15]. <https://www.the-scientist.com/bio-business/companies-use-crispr-to-improve-crops-65362>.
- Teller, A**. 2014. Review of Abby Kinchy's "Seeds, science and struggle: the global politics of transgenic crops": Cambridge, MA: MIT Press, 2012. *J Environ Stud Sci* **4**(4): 364–367. DOI: <https://doi.org/10.1007/s13412-014-0184-x>
- Teo, T**. 2008. From speculation to epistemological violence in psychology: A critical-hermeneutic reconstruction. *Theory & Psychology* **18**(1): 47–67. DOI: <https://doi.org/10.1177/0959354307086922>
- The CRISPR Journal**. 2019. Special Issue: The ethics of human genome editing. Mary Ann Liebert, Inc, publishers. **2**(5). [accessed 2019 Dec 17]. <https://www.liebertpub.com/toc/crispr/2/5>. DOI: <https://doi.org/10.1089/crispr.2019.29072.rba>
- Trauger, A**. 2017. *We want land to live: making political space for food sovereignty*. Athens: University of Georgia Press.
- Travis, J**. 2015. Breakthrough of the year: CRISPR makes the cut. *Science*, Dec 17. [accessed 2019 Sep 22].

- <https://www.sciencemag.org/news/2015/12/and-science-s-2015-breakthrough-year>.
- Upadhyay, SK, Kumar, J, Alok, A and Tuli, R.** 2013. RNA-guided genome editing for target gene mutations in wheat. *G3: Genes, Genomes, Genetics* **3**(12): 2233–2238. DOI: <https://doi.org/10.1534/g3.113.008847>
- USDA.** 2018. Secretary Perdue issues USDA statement on plant breeding innovation, Mar 28. [accessed 2019 Sep 27]. <https://www.usda.gov/media/press-releases/2018/03/28/secretary-perdue-issues-usda-statement-plant-breeding-innovation>.
- USDA/APHIS.** 2017. Importation, interstate movement, and environmental release of certain genetically engineered organisms. Animal and Plant Health Inspection Service, USDA, Federal Register. **82**(12). [accessed 2019 Sep 27]. https://www.aphis.usda.gov/brs/fedregister/BRS_20170119.pdf.
- USDA/APHIS.** 2019. Movement of certain genetically engineered organisms. Federal Register, Jun 6. [accessed 2019 Jun 22]. <https://www.federalregister.gov/documents/2019/06/06/2019-11704/movement-of-certain-genetically-engineered-organisms>.
- USFSA (US Food Sovereignty Alliance).** 2014. Turn the tables on the food crisis: A preliminary report on seeds & seed practices across the United States. Rights of Mother Earth/Defense of the Commons Workgroup. [accessed 2019 Oct 1]. www.usfoodsovereigntyalliance.org.
- Vandermeer, J and Perfecto, I.** 2013. Complex traditions: Intersecting theoretical frameworks in agroecological research. *Journal of Agroecology and Sustainable Food Systems* **37**(1): 76–89. DOI: <https://doi.org/10.1080/104440046.2012.717904>
- Visvanathan, S.** 2005. Knowledge, justice and democracy. In: Leach, M, Scoones, I and Wynne, B (eds.), *Science and citizens: globalization and the challenge of engagement*. London; New York: Zed Books. (Claiming Citizenship: rights, participation, and accountability). Chapter 6.
- Visvanathan, S.** 2009. The search for cognitive justice. In: India Seminar: Knowledge in Question. Seminar publication. [accessed 2019 Sep 28]. www.india-seminar.com/2009/597/597_shiv_visvanathan.htm.
- Wakeford, T and Sanchez, RJ.** 2018. Participatory action research: Towards a more fruitful knowledge. In: Facer, K and Dunleavy, K (eds.), *Connected Communities Foundation Series*. Bristol: University of Bristol/AHRC Connected Communities Programme.
- Walker, R.** 2004. *The conquest of bread: 150 years of agribusiness in California*. New York: New Press: Distributed by Norton.
- Waltz, E.** 2019. Asexual crops whet industry appetite. *Nature Biotechnology* **37**(2): 109–110. DOI: <https://doi.org/10.1038/s41587-019-0031-4>
- Wang, Y, Cheng, X, Shan, Q, Zhang, Y, Liu, J, Gao, C and Qiu, J-L.** 2014. Simultaneous editing of three homoeoalleles in hexaploid bread wheat confers heritable resistance to powdery mildew. *Nature Biotechnology* **32**(9): 947–951. DOI: <https://doi.org/10.1038/nbt.2969>
- WEF (World Economic Forum).** 2018. Innovation with a purpose: The role of technology innovation in accelerating food systems transformation. World Economic Forum System Initiative on Shaping the Future of Food Security and Agriculture, January. [accessed 2019 Oct 1] http://www3.weforum.org/docs/WEF_Innovation_with_a_Purpose_VF-reduced.pdf.
- Weinstein, A.** 2017 Aug 30. The genome revolution: Inside UC Berkeley's CRISPR labs. *The Daily Californian*. [accessed 2019 Sep 26]. <https://www.dailycal.org/2017/08/30/the-genome-revolution-inside-uc-berkeleys-crispr-labs/>.
- White House.** 2019. Modernizing the regulatory framework for agricultural biotechnology. <https://www.whitehouse.gov/presidential-actions/executive-order-modernizing-regulatory-framework-agricultural-biotechnology-products/>.
- Williams, TT and Williamson, H.** 1988. Teaching, research, and extension programs at Historically Black (1890) land grant institutions. *Agricultural History* **62**(2): 244–257.
- Wilson, RC and Carroll, D.** 2019. The daunting economics of therapeutic genome editing. *The CRISPR Journal* **2**(5): 280–284. DOI: <https://doi.org/10.1089/crispr.2019.0052>
- Wise, TA.** 2019. *Eating tomorrow agribusiness, family farmers, and the battle for the future of food*. New York: The New Press.
- Wittman, H, Desmarais, AA and Wiebe, N,** eds. 2010. *Food sovereignty: Reconnecting food, nature and community*. Oakland, CA: Food First Books.
- Wright, AL.** 2005. *The death of Ramón González: The modern agricultural dilemma*. Rev. ed. Austin: University of Texas Press.
- Wright, S.** 1994. *Molecular politics: developing American and British regulatory policy for genetic engineering, 1972–1982*. Chicago: University of Chicago Press.
- Wynne, B.** 1993. Public uptake of science: a case for institutional reflexivity. *Public Understanding of Science* **2**(4): 321–337. DOI: <https://doi.org/10.1088/0963-6625/2/4/003>
- Wynne, B.** 2001. Creating public alienation: Expert cultures of risk and ethics on GMOs. *Science as Culture* **10**(4): 445–481. DOI: <https://doi.org/10.1080/09505430120093586>
- Wynne, B.** 2002. Risk and environment as legitimacy discourses of technology: Reflexivity inside out? *Current Sociology* **50**(3): 459–477. DOI: <https://doi.org/10.1177/0011392102050003010>
- Yapa, L.** 1993. What are improved seeds? An epistemology of the Green Revolution. *Economic Geography* **69**(3): 254–273. DOI: <https://doi.org/10.2307/143450>
- Zhou, H, Liu, B, Weeks, DP, Spalding, MH and Yang, B.** 2014. Large chromosomal deletions and heritable small genetic changes induced by CRISPR/Cas9 in rice. *Nucleic Acids Research* **42**(17): 10903–10914. DOI: <https://doi.org/10.1093/nar/gku806>

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