Towards equitable public sector plant breeding in the US

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ABSTRACT

Plant breeding is central to agriculture, and shifts in plant breeding practices (e.g., hybrid development) and selection goals (e.g., response to synthetic fertilizer) have catalyzed monumental and persistent changes in agricultural production systems of all scales with social, political, economic, and environmental repercussions. While plant breeders are largely trained in the sciences of biology, genetics, and statistics, we posit an ethical imperative to examine the degree of equity with which the benefits of new research and plant varieties are distributed. In the United States, the history of plant breeding parallels the colonial history of agriculture, which compels reflection by current plant breeders about their role in shaping our agricultural system. In this perspective essay, we examine longstanding ideas about equitable food systems through the lens of public plant breeding in the United States. We propose a framework for equitable public plant breeding with respect to both its process and outcomes, and we intend for the ideas presented herein to catalyze reflection, discussions, and actions as the plant breeding community seeks greater equity in the food and seed systems our work supports.

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INTRODUCTION

Human selection of plants with desirable characteristics was integral to plant domestication and was practiced by early agriculturalists worldwide, starting more than 9000 years ago. Today, plant breeding has grown into a profession that frequently requires post-secondary education. In the United States, plant breeders are employed by private companies or by public sector entities like the United States Department of Agriculture (USDA) or universities. Public plant breeders occupy a unique and privileged position in the food system in that their funding is often independent of private interests, their jobs are secure (especially for tenured faculty), and their professional status confers public trust.

Ultimately, we believe that while plant breeding has improved the quality of life for many, there are deeply embedded systemic issues that stifle progress toward equity in U.S. plant breeding and the food systems it supports. Thus, we believe public plant breeders should seek to leverage their unique resources to understand, promote, and practice more equitable plant breeding, with respect to both processes and outcomes, to contribute to more just food and agricultural systems. This essay first briefly summarizes the historical context and current role of public plant breeders in the U.S. agricultural system and then proposes a framework for equitable plant breeding based on core concepts of the food and seed justice movements. We intend for this essay to contribute to discussion of avenues by which we as plant breeders, and the students we train, can enhance equity in both the process and outcomes of plant breeding.

We unequivocally state that the ideas about equity presented herein are learned from movements seeking to dismantle food apartheid, secure seed sovereignty, and promote agricultural sustainability, many of which are led by people with marginalized identities. We encourage readers to engage with primary sources, especially those written by women, nonbinary, queer, and Black, Indigenous, and people of color (BIPOC) authors, and we point to specific titles in the text. We, the authors, are practicing plant breeders or work closely with plant breeders in U.S. and Canadian academic institutions, and we all identify as white. While our white racial identities intersect with various gender, sexual orientation, age, and (dis)ability identities, we recognize the privilege conferred by both our racial identities and the socioeconomic status associated with advanced education. We recognize that our perspectives are inherently limited by the scope of our life experiences, and we look forward to sharpening our understandings of the ideas we begin to articulate here as we engage with calls for equity within our sphere of influence.

I. PUBLIC PLANT BREEDING in U.S. AGRICULTURE

To address concerns of equity in the sphere of agriculture, it is important to directly confront that the roots of contemporary agriculture in the United States grew by the subjugation of land and peoples. Agricultural land was acquired by forcing Indigenous peoples from their ancestral lands (Akers, 1999; Dunbar-Ortiz, 2014). The agricultural economy was then built on 250 years of African slavery, after which racial violence and systemic discriminatory lending practices pushed Black farmers from their land (Gilbert et al., 2002; White, 2018c; Jett, 2020). Discrimination by the USDA against Black farmers resulted in the largest civil rights lawsuit in U.S. history, *Pigford v Glickman*, followed by class action lawsuits from multiple other minoritized groups (Jett, 2020). Redress for these wrongs is still far from complete: people of color represent only 4% of farmer owner-operators and own only 2% of farmland (Horst and Marion, 2019), although comprising 38% of the U.S. population as measured by the 2020 census (US Census Bureau, 2020), and owning more than .

American agriculture was also fueled by the appropriation of plant germplasm and agricultural knowledge from Indigenous peoples and the colonial exploitation of other peoples around the world. The U.S. government took a visible role in germplasm distribution and plant breeding beginning in 1836 by facilitating plant collection expeditions and distributing free seed for (white) farmers to use for crop production and selection of suitable varieties. Over one billion seed packets were distributed in this manner until the program ended due to industry pressure in 1924. The availability of this germplasm was central to the start of scientific plant breeding in the U.S. at the turn of the 20th century (Kloppenburg, 2005). Agricultural research, including plant breeding, was taxpayer-funded and implemented through government programs, yet benefits of this work disproportionately flowed to white farmers. The land grant universities and state agricultural and extension stations that sustained this work were funded by or sited on land endowments seized from Indigenous peoples (Lee and Ahtone, 2020), and because of discriminatory practices in how research was disseminated, Black farmers relied on alternative extension systems led through institutions like the Tuskegee Institute (White, 2018c; Daniel and Baszile, 2021). Women were also excluded as farmers (now 17% of owner-operators; Horst and Marion, 2019) and from plant breeding, with lasting gender disparities (Meints, 2017). The intersection of racial, gender, and other marginalized identities (Crenshaw, 1989) amplifies the degree to which agricultural systems continue to disproportionately serve the interests of individuals with privileged identities.

The landscape of plant breeding changed again in the mid-20th century with the advent of hybrid breeding, which allowed private-sector profitability and the establishment of large seed companies (Kloppenburg, 2005). As plant breeding shifted from a predominately public to a private enterprise (although more extensively in some crops than others), the role of public plant breeders has been continually redefined. These roles are currently defined in the USDA Roadmap for Plant Breeding as “educating the next generation of plant breeders” and “providing public benefits that would be difficult for a private-sector enterprise to justify” (USDA, 2015). This includes pursuing scientific advances that enable tool development, pre-breeding efforts, and cultivar development for crops with little profit potential (e.g., clonally propagated or self-pollinated crops, crops with small markets, or crops that provide ecosystem services). In contrast, the role of the private sector is seen as creating directly marketable products on which a return on investment can be expected.

The current mandate for public plant breeders to pursue research unlikely to enrich private interests implies an intent toward equitable distribution of the benefits of such work for the public good. We believe that public plant breeders should seek to explicitly include equity as a defining part of their role in the U.S. agricultural system. Indeed, the USDA emphasizes engaging with “new rural-urban interactions in food systems — systems that may well need new types of varieties” in addition to rural farmer constituents (USDA, 2015). As urban farms led by people of color have a long history in promoting food justice (Reynolds, 2015; White, 2018c), this statement suggests that the USDA may be willing to fund a broader scope of cultivar development to benefit more diverse constituents. Such funding could build on momentum generated by public plant breeders towards prioritizing cultivar development (RAFI, 2014), and supports the 76% of public plant breeding programs that self-identify as working for the benefit of regional production (Coe et al., 2020). Public plant breeders have the opportunity to extend their current work to include more equitable plant breeding, such that it grows into a foundation for all future work.

II. PROPOSING a FRAMEWORK of EQUITABLE PLANT BREEDING

Two widely read definitions of plant breeding are "the genetic improvement of plants for human benefit" (Bernardo, 2002; p. 3), and "one of agriculture's most effective tools for adapting to new circumstances… a key component in ensuring versatility and adaptability of agriculture systems" (USDA, 2015). These definitions can be expanded to center equity in considering the human benefits of plant breeding. Equity is defined as the proportional treatment of groups in order to produce equal outcomes, whereas equality refers to even treatment of groups (Espinoza, 2008). In an equity model, additional resources would be allocated to benefit historically and currently underserved communities, while an equality model would prescribe equal resources to social groups, regardless of underlying differences in wealth, power, or privilege. We further draw on Gibb and Wittman's (2013) conception of procedural, distributive, and recognition dimensions of food justice. Procedural justice describes equal opportunity to participate in decision-making, while distributive justice describes equitable distribution of benefits and harms; we use the terms 'process' and 'outcomes' to describe procedural and distributive justice, respectively. Finally, justice in recognition relates to the kind of knowledge – and whose knowledge – is considered valid. We attempt to incorporate the recognition dimension of justice into both process and outcome dimensions of equitable plant breeding, even as we recognize that public plant breeding arose from and is substantially anchored in a Western scientific paradigm.

Rather than proposing a definition of equitable plant breeding, we propose a graphical framework that illustrates the dynamic and iterative nature of movement towards equity in plant breeding (**Figure 1**). In this framework, we highlight that ongoing engagement in the processes, outcomes — and intentional connection of processes and outcomes — is central to equitable plant breeding. We also emphasize that there are multiple entry points in working towards equitable plant breeding, and that equitable plant breeding includes integration of multiple aspects of this definition, rather than "checking a box." Finally, we recognize that work towards equity is lifelong and relationship-based. As we engage in reducing barriers to, and building

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capacities for, equity within the plant breeding sector, new systems will emerge, necessitating different approaches to equity over time. This approach of harm reduction and capacity building – rather than theorizing a utopian state of equity in public plant breeding – draws on the capability approach to social change (as reviewed by Robeyns and Byskov, 2021). This framework invites a multiplicity of context-specific actions along with ongoing assessment and problem-solving.

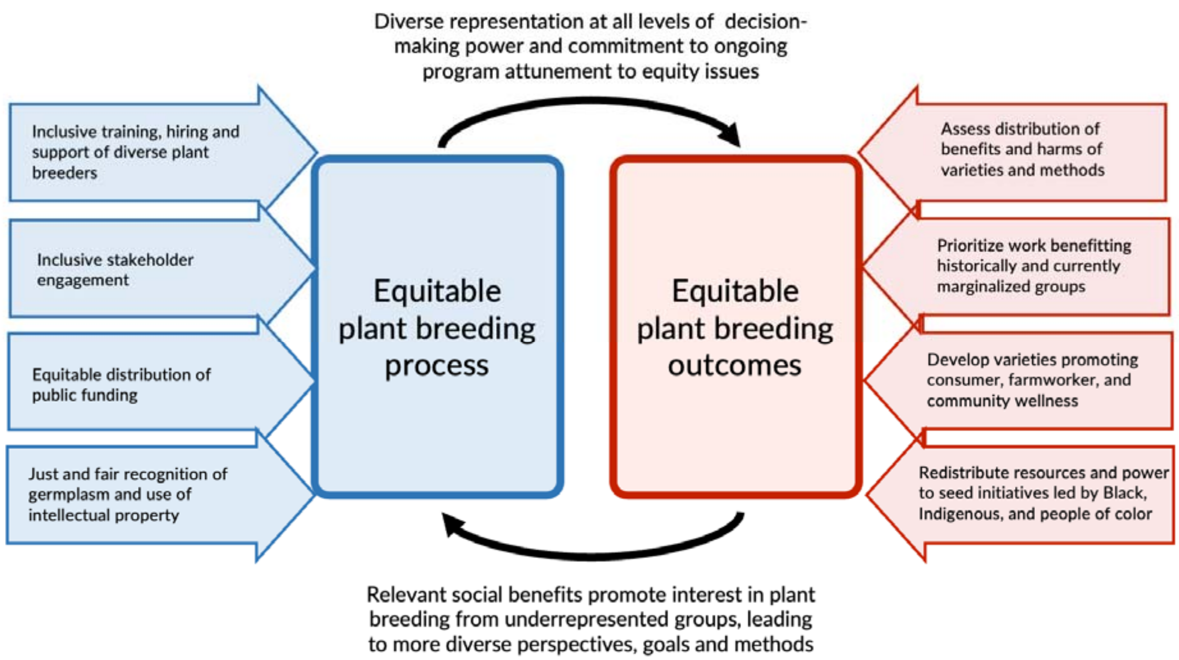

Figure 1. Conceptual diagram of equitable plant breeding, in which the processes (in blue) and outcomes (in red) are intentionally connected (by black arrows) and are interdependent. Different approaches are represented as block arrows to indicate multiple potential 'entry points' towards equitable plant breeding.

III. OUTCOMES of EQUITABLE PLANT BREEDING

Defining attainable and measurable plant breeding goals is critical to making progress towards new plant varieties. Here, we present examples of goals defined to promote equitable plant breeding outcomes. Plant breeding garners global recognition for contributing to society by developing higher yielding, more sustainable, or more profitable crops. However, these outcomes often prioritize economic gain and overlook the many other benefits and harms that diverse communities and individuals may derive from agricultural products. Reviews of plant breeding from ecological, environmental and socioeconomic perspectives have asked "***who derives benefits and who experiences harms from new crop varieties?***" (Kloppenburg, 2005; Jackson, 2011; Pingali, 2012). As public plant breeders, with access to institutional resources, influential platforms, and the potential freedom to prioritize public good instead of solely monetary profits, we have the opportunity and obligation to routinely consider this question in the context of our work. We explore an example of a breeder asking this question in the context of maize breeding in **Box 1**.

Since increasing yield is frequently a primary focus for many plant breeders, it is important to consider how higher-yielding varieties mitigate or maintain socioeconomic inequities within agricultural systems. By lowering food or commodity prices, increasing crop yield is a powerful method of poverty reduction that benefits consumers, as notably demonstrated in the Green Revolution (Evenson and Gollin, 2003; Pingali, 2012). At the same time, lower prices for these commodities can also incur environmental, health, and future economic costs, including through dietary shifts and increased greenhouse gas emissions (Pingali, 2012; Carolan, 2018). In addition, higher-yielding commodity crop varieties can economically benefit some farmers and harm others through the agricultural 'technology treadmill' (Levins and Cochrane, 1996; Wang et al., 2015). Large-scale commodity growers (mostly white individuals; USDA NASS, 2017) who can afford to invest in new varieties benefit initially from the increased productivity relative to other farmers. Once adoption of a higher-yielding variety is widespread, increased system-wide production often lowers the market price, resulting in lower profit margins for farmers who cannot access or afford the improved varieties (Evenson and Gollin, 2003). These economic factors can pressure farmers to continuously adopt higher-yielding varieties to maintain profitability, even if they prefer certain traits of other varieties.

In cases where breeders have the flexibility to select which crops they work on and which traits to focus on, they can prioritize goals that specifically center equity as a desired outcome. As every crop and region differs, there is no universal formula for a plant breeding goal that promotes equitable outcomes, and most goals likely have both costs and benefits to different groups. Moreover, equitable plant breeding goals should be collaboratively defined among all stakeholders, rather than based on a fixed definition from the perspective of one group of people. Those caveats notwithstanding, equitable plant breeding should seek to disrupt power structures in which well-supported constituents continue to be well-supported and those who have been excluded continue to be excluded. We propose that plant breeding goals that center equity could include these elements:

- Understanding how crop trait preferences vary by race, gender identity, or other identities (**Box 2**), and devoting more resources toward research and cultivar development for goals important to marginalized groups.
- Support of community resilience by breeding crops that holistically sustain growers and communities, especially marginalized communities, rather than perpetuate extractive processes that redistribute gains to external shareholders.
- Improving quality and availability of nourishing crops that consumers can afford and use. Nourishing crops include nutrient-dense foods and foods that enhance community or connections to spirituality. Definitions of, and access to, healthful crops are racialized (Alkon and McCullen, 2011; Alkon et al., 2013; Kolavalli, 2020), so culturally relevant concepts of nourishment should be centered.
- Reducing exposure to agrichemicals for farmworkers (Quandt et al., 2004; Arcury et al., 2014) and those who live in proximity to agricultural or agrochemical production (Hill et al., 2019; Tessum et al., 2021) by breeding for reduced agrochemical reliance.
- Support of ecological stability (insect, plant, microbial, and animal communities) and judicious use of limited resources (like water) to sustain communities in the long-term.
- Support of Indigenous-led efforts of seed rematriation (returning seeds to Indigenous communities of origin; White, 2018a), and *in situ* preservation and adaptation of culturally important germplasm (e.g., McGinness, 2019).
- Support of decentralized seed systems, like university seed hubs (Lyon et al., 2021), and seed libraries that maintain germplasm diversity and contribute to community agricultural resilience (Soleri, 2018; Hill et al., 2019; Isbell et al., 2021).
- Using variety release and commercialization practices that prioritize recognition, fairness, and accessibility (see Section IV B).

Prioritizing equity may also broaden interest in plant breeding. 'Generative science' — science shaped by community values and returning direct benefits to that community — has been shown to increase recruitment of individuals from underrepresented backgrounds to STEM fields (Eglash et al., 2016). The USDA (2015) notes that youth without agricultural experience are more likely to pursue well-funded biomedical research than plant breeding: "Even those who do enter plant breeding find that although private-sector demand is high, it is for a limited number of crops, *while there is unmet need for breeding contributions in many other crops and plants* such as forest tree breeding" [emphasis ours]. While the USDA cites forest tree breeding as an example of a sector with unmet need, we argue that focusing on plant breeding priorities with direct benefit to racialized and historically marginalized communities can motivate greater involvement in the field by individuals in those communities.

IV. The PROCESS of EQUITABLE PLANT BREEDING

We explore the *process* toward equity in plant breeding in terms of who determines plant breeding goals — from individual plant breeders to stakeholders to funders — and how germplasm is used. Equity in the process of plant breeding is important because there is no substitute for having more people of color, women, and other people with marginalized identities in positions with decision-making power. As we advocate for equity in public plant breeding, we recognize an inherent tension in that we are also advocating for the continued concentration of resources in the current university and governmental system, which employs us and facilitates public plant breeding. We believe that incremental changes within individual public plant breeding programs can, over time, lead to sustained improvements in the culture and institutional practices, even within this system. At the same time, we recognize the importance of equity-focused seedkeeping and plant breeding initiatives that operate outside of — and may be openly critical of — publicly funded plant breeding. We hope that by normalizing the ongoing discussion of equity within the public plant breeding community, space can be made for mutual learning and support among seed system participants.

IV. A. Inclusive decision-making for plant breeding goals

IV. A. 1. Diverse representation in deciding plant breeding goals

Facilitating inclusivity and diverse representation in STEM fields is a topic of extensive research and important advocacy. We do not review that literature here, but encourage readers to engage with work by Beronda Montgomery, Julie Posselt, and many others (e.g., Whittaker and Montgomery, 2014; Posselt, 2016; Montgomery, 2020). Instead, in this section, we seek to acknowledge that the agricultural discipline of plant breeding faces unique challenges in creating an environment that is safe and productive for scientists of marginalized identities, as American agriculture is intertwined with violence against people of color.

Diverse representation is lacking in many STEM fields, and this deficiency is certainly present in U.S. plant breeding, although underreported. Beginning with Frey (1996), public plant breeders have been surveyed to determine their numbers and funding sources. Notably, however, demographics are sparsely described. No survey we found reported race, disability, sexual orientation, or income. Age was frequently reported; most plant breeders are over the age of 55 (Coe et al., 2020) and most have worked for 21 or more years in their current position (Shelton and Tracy, 2017). Gender identity was only reported in one survey, although it was not a focus of inquiry (142 men and 29 women participated in a survey of public and private plant breeders; Repinski et al., 2011). A 2017 examination of land-grant university websites looking at rank and perceived gender of plant breeding faculty (considering only the gender identities of cis-men and cis-women) found that of 309 active plant breeders, 45 (15%) were women (Meints, 2017). This study identified that women accounted for a decreasing proportion of positions as rank increased (27% of 55 assistant, 16% of 63 associate, and 11% of 191 full professors) (Meints, 2017). While explanations for gender disparities in higher education are documented elsewhere, a survey of faculty in agricultural sciences found that gender inequality and disparity in career outcomes were also influenced by whether or not individuals grew up farming and the degree to which their programs are funded by private sources (Crowe and Goldberger, 2009; Buttel and Goldberger, 2009; Goldberger and Crowe, 2010). These disparities are likely compounded for individuals with intersectional marginalized identities (Crenshaw, 1989).

At the university level, there are opportunities for public plant breeders to thoughtfully engage in recruitment and, importantly, retention of diverse plant breeders, and we highlight some examples here. As public plant breeders seek to diversify their work groups, it would be worthwhile to implement approaches that have been effective across STEM fields (e.g., eliminating GRE requirements for graduate students (Posselt, 2016); providing inclusive mentoring (Montgomery, 2021); and making field work safer (Demery and Pipkin, 2021)). Cox et al., (2021) recently shared their perspectives as early career Black plant scientists (undergraduate to postdoc) on ways to better support and retain Black scientists. Specifically, they highlight the need for community belonging (through cohorts or social networks), responsive mentorship, and training and funding opportunities for underrepresented minority students.

We encourage public plant breeders at universities to carefully reflect upon the scientists that are featured in their courses, especially introductory courses. American agricultural historical and contemporary narratives frequently erase contributions of people of color. For instance, Penniman (2018) writes that dominant agricultural narratives almost exclusively elevate white people as leaders in sustainable farming, so learning about Black agricultural leaders like Fannie Lou Hamer and Booker T. Whatley was "deeply healing" (p. 3). A recent example of developing a new course on Indigenous foodways at a major public university highlighted the positive outcomes of greater representation in the curricula, including presenting an alternative perspective on our food system new to many students (Luby et al., 2021). In all courses, understanding and challenging the biases embedded in plant breeding terminology can further cultivate an inclusive learning community (**Box 3**).

In addition, when possible, plant breeders could seek opportunities for field work for students in safe and inclusive spaces by creating new collaborations. For instance, Penniman (2018) and Black Farmers United NYS write that agricultural training programs must be available for new Black farmers that are led by Black farmers, in part because white-led programs lack cultural relevance. Individuals who direct student research should attempt to build partnerships with BIPOC-led organizations that allow students to ask exciting research questions in spaces that are safe and productive.

Finally, and critically, plant breeders must provide instruction on setting and contextualizing plant breeding goals. In plant breeding curricula, we often teach students plant breeding methods with the goal assumed to be worthwhile. Instead, to train students to contribute to equitable outcomes, it is essential to teach students how to consider direct and indirect effects of their plant breeding goals, potentially including collaborations with experts in other fields like sociology, economics, policy, or environmental science. That is, we advocate for building equity competencies in plant breeding students, as articulated by Valley et al., (2020) in the context of sustainable food systems education. Equity competencies center around awareness of self, others, interactions between self and others, and systems of power and oppression that shape those interactions. An equity competency model builds the drive and skills to take actions that disrupt inequities, and crucially, building equity competencies among plant breeding students requires the same from plant breeding faculties, administrations, and university communities, as discussed in Section V.

IV. A. 2. Inclusive engagement with a diverse community of stakeholders

Typically, an individual who leads a plant breeding program consults with stakeholders at various stages of the plant breeding process. By working with stakeholders on a participatory basis, plant breeders can more accurately set their plant breeding goals to increase adoption of varieties (Ceccarelli, 2015). Stakeholders may include growers, seed companies, processors, home gardeners, chefs, and consumers, depending on region and crop. However, if the diversity of identities or interests represented by stakeholders is narrow, plant breeders' capacity to advance equitable plant breeding goals will be limited.

In some cases, stakeholder information is sparse; Black Farmers United advocates for surveys that "identify who and where our state's black farmers are," as even that baseline of information is not easily attainable (Black Farmers United NYS, ND). Surveys to understand the importance of traits for plant breeding should track demographic data, as relative importance and benefits accrued may differ along racial, gender, and intersectional identities (see **Box 2**). Currently, availability of survey data on grower trait preferences for U.S. crops is unevenly available and rarely includes demographic information like racial or gender identity. For example, of four recent surveys of grower trait preferences for organic crops (Lyon et al., 2015; Brouwer and Colley, 2016; Hultengren et al., 2016; Baker et al., 2020), only one Lyon et al., (2015) reported participant gender identity. Including (voluntary) identity questions in surveys intending to gauge plant breeding trait preferences for growers and consumers would provide opportunities to equitably address differences in varietal preferences through plant breeding efforts. Further, collaborating with a social scientist in survey design would also aid in interpretability of subsequent results.

It is also important to increase the reach of surveys, especially to people currently underrepresented in agricultural research. By continuing to include only those who have been historically included, or in existing networks, the inequities of long-term institutionalized policies that favor white and large-scale producers will be perpetuated (Horst and Marion, 2019). Importantly, including more stakeholders is critical in defining equitable goals, as goals should be community-defined. For instance, the 2017 Census of Agriculture reported that 1.4% of agricultural producers were Black and, of those who specialized in crops (rather than livestock), more grew ‘specialty’ or ‘other’ crops (30%) than grain or oilseed crops (7%), and most operated in the South (USDA NASS, 2017). With this information, it becomes clear that surveys that focus on adaptation for southern regional markets and provide space to describe crop type (so that information is not lost in broad categories like ‘specialty’ and ‘other’) could inform a more equitable distribution of resources to better support Black farmers.

IV. A. 3. Sourcing funding for plant breeding work that promotes equity

Funding sources also influence plant breeding goals. Grants from the local scale (e.g., regional commodity organizations), to federal scale (e.g., USDA) fund about 30% of U.S. plant breeding work (Coe et al., 2020). It is important to understand how the USDA allocates research funding, in terms of topic and applicant demographics. While we are unaware of such an analysis of USDA funding, researchers found persistent racial disparities in National Institutes of Health (NIH) funding (Taffe and Gilpin, 2021). This disparity was in part attributable to Black scientists submitting more proposals than white scientists on topics like community health versus molecular biology, and the NIH has a higher funding rate for the latter (Hoppe et al., 2019).

We encourage public plant breeders to seek transparency from funding agencies by asking which people with which interests are applying and being funded. In addition, public plant breeders should advocate for more just distribution of funding. Public plant breeders have been at the vanguard of promoting best practices in intellectual property (Dawson et al., 2018), and prioritizing cultivar development in Farm Bill funding (RAFI, 2014). In advocating for more equitable distribution of funding, public plant breeders should uplift existing efforts by marginalized communities, and ensure that people with marginalized identities have power in determining how to distribute finite funding. Stevens et al., (2021) describes that for the NIH, an equity-driven funding pipeline includes a defined equity policy and centering antiracism in reviewing. Those principles can be applied also for the USDA. An example of a competitive granting program that prioritized funding for underserved communities is the Organic Farming Research Foundation's 2021 request for proposals in which they state: "We believe it is critical to foster the next generation of researchers and support historically underserved and marginalized communities, while also ensuring all farmers have the most up-to-date and science-based information. OFRF is reserving half of our grants for BIPOC applicants" (OFRF, 2021).

IV. B. Equitable use and recognition of plant breeding germplasm

Plant breeding relies on access to plant germplasm to develop new varieties. Movement towards equity in plant breeding hinges on recognition of germplasm sources, which in turn can facilitate sharing of monetary gains and culturally appropriate use of germplasm. Recognition of germplasm sources requires sensitivity to — and learning about — the cultural values, history, and current sociopolitical positions of people connected with crop origins. For instance, Indigenous seed keeper Rowen White writes, "indigenous and farming people from around the globe didn't just complacently give up our rights to care and steward our ancestral seeds…no it has been a violent transition, people robbed of their rights by large corporate campaigns to disconnect people from their seeds, or manipulated into thinking that progressive change to new hybrid varieties will ease the workload or increase the yield" (White, 2018b). Indigenous writer and scientist Robin Wall Kimmerer also writes, "Grain may rot in the warehouse while hungry people starve because they cannot pay for it… The very earth that sustains us is being destroyed to fuel injustice" (Kimmerer, 2013, p. 376). Indeed, movement toward greater equity in plant breeding is inextricable from the return of land and power to Indigenous peoples, which Indigenous food sovereignty activists and scholars view as essential to lasting community health (Kepkiewicz, 2020, citing Indigenous Circle, Food Secure Canada). While defining 'appropriate' uses of crop germplasm is not easy, plant breeders should consider how using particular germplasm affects communities of origin and engage with diverse communities of stakeholders, including Indigenous groups with cultural ties to the crops.

There are also issues of financial reparations and intellectual property restrictions for crop germplasm. Much of our agricultural germplasm has been taken from the Global South, yet profits are not shared: this is the basis of benefit sharing outlined in the 1992 Convention on

Biological Diversity (which the U.S. did not ratify) and the 2010 Nagoya Protocol (which the U.S. neither signed nor ratified). Relatedly, a major critique of the CGIAR centers is that they efficiently extract germplasm from developing countries for U.S. interests (Kloppenburg, 2005). While most plant breeders have limited capacity to influence international treaties, public plant breeders can work with their institutions to better align intellectual property policies with notions of equity.

Public plant breeders regularly source germplasm from public repositories, share germplasm with other plant breeders, and release new varieties for public use. However, germplasm use is often limited by Material Transfer Agreements (MTAs, in the case of breeding material) or various forms of intellectual property restrictions (IPRs, in the case of released varieties, e.g., Plant Variety Protection). Agreements vary by institution and crop, but both MTAs and IPRs can prevent the recipient from making crosses or saving seed (Shelton and Tracy, 2017). While MTAs are important in obliging equitable benefit sharing from global germplasm exchange, especially for counties of origin (FAO, 2009), implementing restrictive MTAs can limit plant breeders' capacity to operate (e.g., by narrowing the diversity of material available for crossing). We see overuse of restrictive MTAs that limit exchange between U.S. public institutions or privatize public resources within the Global North as an obstacle to equitable plant breeding. The limited access to germplasm affects not only public breeders but also farmer-breeders, seed savers, and others working outside formally recognized organizations. In some cases, plant breeders have used IPRs to restrict access to plant varieties that are culturally important in the Global South or to Indigenous groups in North America. A famous example of this biopiracy is the patenting of the Enola bean despite a long history of use in Mexico (Rattray, 2001).

Public plant breeders have developed guidelines for addressing intellectual property issues. A 2016 conference on intellectual property rights for public cultivar development recommended that public plant breeders develop a professional standard for germplasm exchange and variety release that allows for future breeding (e.g., through Plant Variety Protection Act or the Wheat Workers' Code of Ethics) (Dawson et al., 2018). This standard promotes access for plant breeders and seed savers, while acknowledging the tension that released varieties contribute financially to some plant breeding programs. Other public plant breeders have proposed the Open Source Seed Initiative (OSSI), which establishes a commons for plant germplasm in seeking to ensure no current or future practitioner can place any type of intellectual property restrictions on the germplasm (Luby et al., 2015).

Just as intellectual property restrictions vary by institution, so do royalty-sharing agreements arising from MTAs or IPRs. Royalties generated by publicly developed cultivars may be returned to breeding programs to support future cultivar development (on average, 5.5% of public plant breeding programs budget comes from royalties, with substantial variation; Coe et al., 2020), but funds may also be diverted to other university purposes or to the plant breeder personally (Dawson et al., 2018). In building towards equitable plant breeding, plant breeders (and their institutions) should prioritize the continued security of the breeding program and equitable food systems in distribution of royalties, rather than rewarding individuals. Opportunities to engage stakeholders in decisions about royalty distribution should also be explored, including ways to value current and historical contributions of communities to the crops of interest. For example, Fedco Seeds, a seed and plant breeding cooperative, distributes a portion of royalties from varieties connected to local Indigenous peoples and Black foodways to relevant regional non-profit organizations (Fedco Seeds, 2021).

V. STEPS for PLANT BREEDERS SEEKING to BUILD EQUITABLE PLANT BREEDING PROGRAMS

Here, we build on the equity competency model of Valley et al., (2020) to synthesize a process by which plant breeders can engage in reflection, discussion, and thoughtful actions towards greater equity in their plant breeding programs. We provide a series of questions (**Box 4**; and as a printable PDF in **File S1**) for use by lab groups, journal clubs, or faculties as they begin or iterate this process.

1. Self-education

It is important for plant breeders to be aware of agricultural and plant breeding history to contextualize our plant breeding priorities and the paths by which we attained our roles. First, we encourage plant breeders to familiarize themselves broadly with agricultural history and current issues faced by stakeholders (growers, consumers) with marginalized identities. We also encourage plant breeders to seek in-depth knowledge about their regional history, and how their professional position and work is situated in the region. Finally, plant breeders should also add to their knowledge about the crops they breed, including cultural histories and means of acquiring and disseminating germplasm.

2. Evaluation

Plant breeders must evaluate their own programs with willingness to acknowledge processes and outcomes that could be improved. To begin, plant breeders can ask: Who benefits from my program's plant breeding goals? How does my program's allocation of resources reflect equity? Who do I define as a stakeholder? To what degree is stakeholder input prioritized in defining breeding goals and methods? Importantly, plant breeders should seek to evaluate their responses in the context of the crops and regions in which they work. Plant breeders are trained in evaluating germplasm in particular environmental contexts, and they may frame this evaluation in a similar way. In addition, plant breeders should be open to peer evaluation and may benefit from critical and compassionate insights from others in the field. We believe that normalizing discussion around equity goals — in the context of iterative, inherently imperfect community improvement rather than punitive assessment — is critical to building sustained movement towards equity in plant breeding.

3. Shift plant breeding priorities to support equitable processes and outcomes

Plant breeders should take steps to shift their breeding goals and processes such that they move towards promoting equity in our food and agricultural systems. Frameworks for direct involvement of growers and consumers are established as participatory plant breeding systems and can be applied to this work (e.g., Dawson et al., 2008; Entz et al., 2015; Healy and Dawson, 2019). In doing so, plant breeders could seek to center ideas of equity in outcomes and process into existing projects and new proposals. For white plant breeders and others with relative privilege, it is critical to note that individuals who want to address inequities can still cause harm, through attitudes like saviorism and through missteps like overshadowing community activists for media attention or funding (Penniman, 2018; White, 2018c; Black Farmers United NYS, ND). For projects that involve communities of color, the best practice is for people of color to retain leadership of the project and ownership of the results, and trust should be built through supporting roles like assistance with grant writing or networking (Penniman, 2018). Such arrangements may conflict with requirements of granting agencies and academic institutions, inviting discussions, negotiations, and creative problem-solving with stakeholders.

4. Build a foundation for sustained change

Today in 2022, there is momentum towards addressing inequities in the US, but these ideas must be institutionalized to build lasting change. For instance, we can change funding and professional reward structures (e.g., hiring and tenure) to promote goals for equitable food and agricultural systems. While public plant breeders may not need to demonstrate the financial gains expected of plant breeders working in the private sector, those in universities must often seek tenure, consolidate support from their institutions, and maintain a favorable professional reputation. We should seek to align those career drivers with goals that support more equitable agricultural systems. We must also ensure scientists are supported at all career stages (from undergraduate to faculty or professional) in having safe and productive spaces to do impactful work and, importantly, create space for people to pursue careers in agriculture at all levels of decision-making power. We must prepare ourselves for the fact that the changes proposed here — like promoting leaders with diverse perspectives, broadening stakeholder involvement, or rethinking trait prioritization — will meet significant inertia in a system built and maintained to support the groups who created it. However, continuing the status quo will not improve equity within agricultural systems. While new technologies like gene editing are often lauded for their potential to transform societal outcomes, new technologies can also perpetuate the same inequities. As emphasized, we should question and shift the projects and traits that we prioritize in our own programs, but we should also work to reform the institutions within which we work to encourage and facilitate such shifts so that equity-driven work is normalized.

VI. CONCLUDING REMARKS

Plant breeding shifts plant traits and, as plant breeders, we can define new directions for both trait shifts and cultural shifts that move our agricultural and food systems towards greater equity and justice. U.S. agricultural history is etched into our seeds and includes scars of violence, oppression, and theft alongside expressions of sustenance, hope, resilience, and change. As plant breeders, we must recognize this and work intentionally and actively so that our seeds propagate less injustice and inequity and embody the values and vision of increasingly diverse stakeholders, communities, and plant breeders. We must promote plant breeding goals set by people, centering those with marginalized identities and recognizing both the profit motives and humanity of people working within corporations. In addition, we must attune ourselves to equity throughout the process of plant breeding work, recognizing that equity competencies are built not only within individuals but among them, in our lab groups, departments, and collegial organizations. There are many entry points to increasing equity within public plant breeding — through student and faculty recruitment, funding priorities, stakeholder engagement strategies, and more — and we encourage individuals and departments to take steps, assess, and iterate. This work is lifelong, but it is essential to the ethical integrity and mission alignment of public plant breeding.

Public plant breeders occupy a unique position in our agricultural system where most are publicly funded (and, we argue, thus compelled to maximize the public good done by their work) and are integrated in the academic community (and what is the purpose of academia other than to ask challenging questions?). Public plant breeders have platforms to influence policy, to amplify ideas, and to produce new cultivars through processes that embody an ethic of service to the public good. Plant breeders also have access to enormous resources — from genome sequencing to collaborative variety trialing networks to grant funding — allowing us to pursue ambitious plant breeding objectives. As stewards of this substantial power, we must acknowledge that what we can do and what we should do are separate questions, where the latter deserves greater emphasis (Kimmerer, 2021). While addressing the roots of injustices in our food systems requires action at broad scales, public plant breeders have a responsibility to use our unique sphere of influence to promote equity both through the process and as an explicit goal for the outcomes of plant breeding.

SUPPLEMENTAL MATERIAL

Supplemental File 1. Discussion questions handout

AUTHOR CONTRIBUTIONS

LJB led this writing project by inviting co-authors, convening writing discussion sessions, articulating and integrating feedback, delegating writing, and identifying boundaries for the work. Co-authors have written sections, as well as commented, critiqued, and substantially contributed to the writing and vision of the whole. We have jointly considered and iterated the writing over several sessions in a spirit of seeing beyond where history has brought us thus far.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Box 1. Who derives benefit and who experiences harm? An example in the context of maize breeding.

For public sector plant breeders working on a commodity crop such as maize, equity issues may become the central guide for their work. We talked to Margaret Smith, Professor of Plant Breeding and Genetics Section at Cornell University, who experienced this firsthand. Prof. Smith's work with maize began as a graduate student working with the International Maize and Wheat Improvement Center (CIMMYT) and then joining the Tropical Agriculture Center for Research and Teaching (CATIE), where her work focused on smallholder farmers growing maize. When she evaluated trials on smallholder farms, she quickly realized that the improved varieties from large breeding programs selected under optimal conditions were not performing any better than what farmers already had. "*My job was to figure out what a maize variety needs to thrive on a hillside with no fertilizer and intercropped with climbing beans in Honduras… So my earliest job was steeped in thinking about what breeders are doing for smallholder, food insecure farmers who have a half hectare of land and need to feed their family all year*," she recalled.

Prof. Smith's experience working with smallholder trials helped direct her breeding goals to focus on improving stress tolerance traits through participatory breeding approaches as a way to engage stakeholders who had been traditionally excluded. But she also saw potential harm this work could have had on smallholder farmers they worked with, by placing a time and resource burden on participants. This was in contrast to all the investment, effort, and funding that multinationals and large research organizations put into delivering ideal maize varieties to well-endowed farmers. Prof. Smith said: "*The only people being asked to invest time and effort to develop varieties that would benefit them were the people who had the least time… How can we make it feel like a worthwhile investment of energy, time, and labor? I think it is incumbent on us to think of the resource demands we are placing on farmers*." Considering both the distribution of the benefits of maize breeding and the impacts of breeding methods themselves were important in shaping Prof. Smith's priorities.

When Prof. Smith returned to the U.S. to work as a public sector corn breeder at Cornell, she needed to think carefully about her role: "*When you work on field corn, the overwhelming focus is on the commercial seed sector. In companies, you want varieties that will sell lots of* *seed, so the incentives are very much focused on the broadly-adapted, large market, major types. The others are too small a market [for profitable investment].*" While acknowledging that there cannot be a separate variety for every farmer, she has found that addressing unmet needs has been her way to make a difference as a public sector breeder. Focusing on "niches" of improving disease and insect resistance traits that were longer term and more complicated to breed for, developing varieties for organic systems, or maize adaptation to cover cropped systems became her means of contributing to farmers. However, funding has been a challenge in niche spaces: "*When I talk to people in the USDA or Federal Government about support for public plant breeding they respond, 'well, you work on corn!'... Yes, there are hundreds of corn breeders, but the question is what is being addressed and what is not being addressed, and how important that is*."

Thinking about how to shift norms of public sector breeding programs to be more centered on equity, Prof. Smith is hopeful that the confluence of climate change with agroecosystem change, growing interest in local foods, and disruption of supply chains by the pandemic "*creates some space to address more niche needs and not the large target environments for U.S. No. 2 yellow dent corn.*" She said, "*The pandemic has caused us all to uncouple things, and we can think about what connections and what patterns we want to re-establish or change in terms of who we are breeding for*."

Box 2. Drawing inspiration from gender equality and international plant breeding

International agricultural research for development has long been shaped by donor goals and strategies. While at times problematic, the focus of major donors on gender equality (e.g, BMGF, 2019; USAID, 2020) has pushed plant breeding programs to include gender and social difference in setting breeding priorities. There is mounting empirical evidence for the importance of gender in adoption of new varieties (Fisher and Kandiwa, 2014), as well as systematic documentation of differences in trait preferences between men and women for most major food security crops (Weltzien et al., 2019). Trait preferences follow gender divisions of labor and market access (Christinck et al., 2017), and they are shaped by gender-based constraints to information and resources. For example, women produce sorghum in lower fertility fields in Mali because gender norms dictate that they are allocated fields at the end of the crop rotation when fields are nutritionally depleted, which may be driving them to select early and tall varieties (Leiser et al., 2018).

While most attention around gender analysis in plant breeding internationally has focused on gender disaggregation, analyses of intersecting social identities and household characteristics are emerging. An early example of this thinking is documentation of poorer and widowed women in Malawi preferring bitter cassava varieties to prevent theft, since these varieties require undesirable long processing times (Chiwona‐Karltun et al., 1998). Subsequent work in cassava in Nigeria revealed similar findings, where differences in trait preferences between men and women were greater if they lived in food insecure households (Teeken et al., 2021). This matters because intentionally designing breeding programs to be gender responsive has potential for positive social benefits for women (Tufan et al., 2018), emphasizing the need for equitable plant breeding processes (**Figure 1**). This is most poignantly documented by (Galiè et al., 2017): women who participated in a gender-sensitive participatory barley breeding program in pre-war Syria increased their recognition as farmers in their communities, with program activities opening spaces to question and challenge discriminatory gender norms.

The above citations only scratch the surface of the body of scholarship around gender and social differences and how these differences shape adoption, trait preferences, crop management, and seed systems. The lack of analogous studies in the U.S. severely limits positive interventions for equitable plant breeding processes and outcomes. Without carefully designed participatory

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social research, we may fall short of formulating effective policies and interventions to build inclusive plant breeding systems. Studies could examine, for example, what farming systems and crops farmers who identify as women, nonbinary, queer, and Black, Indigenous, and people of color (BIPOC) choose and why; how inequitable access to productive resources such as land, inputs, credit, social capital and information affect crop choice, varietal choice and even trait preferences; and perhaps most importantly, how private and public sector plant breeding programs in the U.S. can be systematically designed to reach, benefit and empower farmers who identify as women, nonbinary, queer, and BIPOC.

Box 3. The legacies of language

The technical language of plant breeding facilitates the development of a professional community by offering a way to communicate over time and space. The language of plant breeding emerged with the field itself around the turn of the 20th century, and as such it is infused with the cultural assumptions of that era around human relationships with land, plants, and seeds, as well as racial hierarchy and gender roles. We call for critically considering the terminology we use to communicate about plant breeding so that we intentionally choose language that embodies equity and justice, and we outline examples here.

Plant breeders rely on genetic variation to conduct selection and use the term 'germplasm' to describe plants, seeds, and propagules that harbor such variation. When conceptualized as germplasm, plants and seeds may represent resources to be stewarded, employed, or exploited. Many Indigenous worldviews, however, relate to plants and seeds as relatives or beings with whom to interdepend, rather than objects to manipulate or own (Morrison, 2011; Kepkiewicz, 2020). The contrast in these worldviews highlights the intrinsic limitations of the word 'germplasm'. We encourage plant breeders to engage with diverse and nuanced Indigenous perspectives (as they are offered) on relationship with land, plants, and seed (e.g., Coté, 2016; Martens, 2018; Daigle, 2019). Importantly, engagement with Indigenous food sovereignty literature and particular Indigenous groups should be approached with humility, a desire to learn, and a willingness to be challenged, rather than assimilating Indigenous terminology or concepts into a fundamentally unchanged Western structure (Skinner et al., 2018). Thus, our call here is less to adjust our language around germplasm than to use its implications as an impetus to expand our understanding and imagination around our relationship with plants, the land, and the original stewards of the land now known as North America.

Selection within variable plant populations requires measurements of both variability and the designation of certain phenotypes as superior, or desired. This paradigm is rooted in evolutionary biology — indeed, the concept of variation is central to Darwin's theory of evolution — but is also inextricable from that of eugenics, "an 'applied science' that seeks to improve the genetic composition of a population by controlling reproduction." (Subramaniam, 2014; p. 46). Moreover, the field of biometry was "generated as a toolbox for eugenics" (Louçã, 2009) and statistical concepts like regression and correlation were invented in order to express variation in service of eugenic goals (Rohlfs, 2020). As plant breeders, we cannot escape assigning value to certain phenotypes and thereby to certain genotypes, and we will continue to use statistical methods to characterize populations and facilitate selection. Shifting language around genetic superiority, then, is not about denying that certain traits are desirable. Instead, our goal is for plant breeders to explicitly *contextualize* the agricultural and food systems for which they are desirable and to recognize who benefits or is harmed from the designation of a trait as useful.

Generating variation for plant breeding programs is predicated on recombination during meiosis and, often, on sexual reproduction. To cultivate an inclusive space, plant breeders should avoid conflating sex and gender, assigning genders or gendered terms to plants (as plants do not have gender), and projecting anthropomorphic social constructs of gender onto plants. Examples of gendered terms include ‘maternal’ and ‘paternal’ or ‘masculine’ and ‘feminine’, and are not appropriate in discussing plant sexual reproduction or plant anatomy. While the terms ‘male’ and ‘female’ are technically accurate descriptors of plant sex (Stuhlsatz et al., 2020), those terms have gendered implications and communicate that plant sex is binary. To avoid gendered implications, an alternative vocabulary could be ‘pollen’ and ‘seed’ parents or plants, rather than referring to ‘male’ and ‘female’ parents or plants, respectively. Students may also appreciate instructors discussing the fact that in most plant species, individuals are hermaphroditic and that plant sex expression is not always static.

Box 4. Discussion questions. We propose these questions as a resource for plant breeders to bring to lab meetings, workshops, or other settings to stimulate reflection and discussion. The questions are adapted from the ‘equity competencies’ described by Valley et al., (2020). A downloadable PDF is available as **File S1**. We recognize that participants may have divergent viewpoints. To promote respectful dialogue, we encourage groups to follow guides for intergroup dialogue, like the LARA (listen, affirm, respond, add information) method (https://idp.cornell.edu/idp-guides/idp-guide-using-lara/).

Knowledge of self

- How did I become interested in plant breeding, and why do I engage in plant breeding now?
- Who are my professional role models, and why do I admire them?
- In what ways do I view plant breeding as a way to do good in the world, and who is intended to benefit? In what ways do I perceive harm arising from plant breeding, and who is harmed? And, what does ‘benefit’ and ‘harm’ mean to me?
- How do I define 'success' for myself as a plant breeder? How does this compare or contrast with the way my institution defines success? How do these conceptions of 'success' support equity versus inequity in my work?
- How were goals determined for the plant breeding projects I work with? How could I imagine them changing, and why would I make those changes?
- What changes have I implemented (or am I considering) within my program to make its process or outcomes more equitable? Using Figure 1, which ‘entry points’ to more equitable plant breeding are most and least accessible to me, and how can I access more ‘entry points’?
- How can I tell if my efforts towards equity, inclusion, or harm interruption are working?

Knowledge of others and one’s interactions with them

- How would I describe my interactions with my colleagues and/or students? Who is included and excluded from my interactions, and why?
- How do I define and evaluate success in plant breeding or other professional endeavors for my students and mentees? To what degree is this process collaborative?
- Who are the stakeholders in my plant breeding projects, and how do I interact with them? How do I seek to understand their identities, perspectives, and goals?

- How am I building (or could I build) sustained, meaningful relationships with marginalized groups that do not hinge on, for instance, a grant opportunity?
- How do I seek out opportunities to be more inclusive or an ally in building a work team or engaging with stakeholders?
- How do I evaluate who is impacted by my plant breeding work?
- To what degree do I connect the process of plant breeding (interactions with students, colleagues, stakeholders, funders, etc.) to the outcomes of plant breeding? An example is given in Figure 1.

Knowledge of systems of oppression and inequities

- What do I know about the historical trajectory of plant breeding, and what beneficial and harmful outcomes can I think of (considering environmental, economic, political, social justice, interpersonal, health, or other outcomes for a particular crop or geographic context)? Who gets to decide? For instance, are some perspectives or contexts considered more credible or important?
- How does the professional atmosphere of academia, government agencies or other institutions foster or hinder building relationships with potential stakeholders?
- How can I recognize, incentivize, or support others' work towards more equitable plant breeding? Can I do so in a way that is integrated with, rather than separate from, typical career development structures?
- Reflecting on the 'entry' points on Figure 1 that involve systems beyond myself as an individual plant breeder, how can I work to reduce systemic barriers and advocate for systemic change?
- What sources have been helpful in my learning about historical and current food system inequities? How am I continuing my learning in this area?
- What questions do I still have, and how can I go about addressing these questions?