Anticipating Farmer Outcomes of Three Genetically Modified Staple Crops in sub-Saharan Africa: Insights from Farming Systems Research

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> "If there is one thread that runs through all policy discourses on technology, it is the need for wise anticipation" - Shelia Jasanoff, *The Ethics of Invention*, p.249

Abstract: Conventional ex-ante evaluations rely on a mix of economic, environmental, and social indicators to assess the potential impacts of Genetically Modified (GM) crops prior to their commercial release. While these predictive studies have produced useful knowledge, they have also consistently overestimated the ex-post outcomes of GM crops for African smallholder farmers. Yet these same assessment methods remain the dominant approach to project farmer outcomes for a new suite of soon-to-be commercialized GM staple crops. The research presented in this paper offers a different evaluative approach for these new GM crops by taking inspiration from farming systems research (FSR). We use the conceptual starting point of FSR scholarship—the farming system—to conduct an exploratory predictive analysis of three GM crops currently in the experimental pipeline: Water Efficient Maize for Africa (WEMA) in Kenya, disease-resistant matooke banana in Uganda, and Bt cowpea in Burkina Faso. Our findings suggest that the lofty projected benefits of these crops are unlikely to be realized by many, if not most, smallholder farmers due to incongruences with the farming systems they are designed to benefit. This research demonstrates the importance of using farming system-based evaluation methods to better anticipate likely farm-level outcomes of new breeding technologies.

Keywords: Genetically Modified crops, Africa, ex-ante evaluations, farming systems research, maize, matooke banana, cowpea

1. Introduction

Advocates trumpet Genetically Modified (GM) crops as a tool that can boost agricultural productivity and alleviate food insecurity in sub-Saharan Africa (Juma, 2015; Lynas, 2018). The intended beneficiaries are smallholder farmers, who run semi-subsistence or small market-oriented farms and businesses using primarily family labor on small plots of land with holdings of fewer than four hectares (Lowder et al., 2016; AGRA, 2017). Over the past twenty-five years, GM varieties of cotton, maize and soybean have been released across six different African countries: South Africa, Burkina Faso, Sudan, eSwatini, Nigeria, and Kenya. All GM varieties currently grown by African farmers are first-generation GM crops – proprietary technologies designed to maximize productivity in commodity crops by focusing on either insect-resistance or herbicide tolerance.

Proponents reserve their greatest enthusiasm for soon-to-be-commercialized second-generation GM crops, or GMO 2.0, which differ from their first-generation predecessors in two crucial ways. First, GMO 2.0 are the result of public-private partnerships (P3s), which waive the intellectual property rights associated with the GM traits, meaning that farmers are not charged an additional technology fee and do not face restrictions regarding the recycling or reuse of planting materials. Second-generation GM crops are further distinct from their first-generation predecessors in that they focus primarily on the transfer of GM traits into African staple crops, i.e. food and subsistence crops grown by smallholder farmers such as cassava, millet, cowpea, cooking banana, pigeon pea, sweet potato, and sorghum, many of which have been largely ignored by private investment and research (Schnurr, 2015). These second-generation GM crops

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have yet to reach the hands of farmers but have become important exemplars of the potential for new breeding technologies to address poverty and food insecurity on the continent.

A close examination of the empirical record of first-generation GM crops raises important questions about whether second-generation GM crops will benefit smallholder farmers. Of particular concern is the gap between the optimistic assessments of potential benefits offered by ex-ante evaluations and the ex-post experiences of farmers. The first and most widely adopted GM crop to be introduced on the continent was Bt cotton, an insect-resistant cotton released first in South Africa in 1999 and subsequently in Burkina Faso in 2008. Smallholder farmers rapidly embraced Bt cotton upon its initial release in South Africa's Makhathini Flats, which signaled the first evidence that GM crops could help poor African farmers (Thirtle et al., 2003). But longer-term research revealed that South Africa's early success hinged on a fragile supportive context including easy credit and a restrictive buying arrangement that penalized those opting to grow non-GM varieties (Witt et al., 2006; Schnurr, 2012). Once these enabling conditions disappeared, so too did smallholder farmer enthusiasm for Bt cotton. In Burkina Faso, ex-ante evaluations predicted average yield increases of 30% (Vitale et al., 2011). However, ex-post farm-based research, reported average yield gains of only 13% (AICB, 2015), alongside issues with lint quality and highly variable profits (Vognan and Fok, 2019). While approximately 140,000 smallholder farmers grew Bt cotton at its peak in 2014 (James, 2014), Bt cotton was abandoned entirely in 2016, due to severe economic losses associated with Bt cotton's inferior lint quality (Dowd-Uribe, 2014; Dowd-Uribe and Schnurr, 2016; Luna and Dowd-Uribe, 2020)

The gap between the optimistic scenarios offered by the anticipatory evaluations of Bt cotton and the lived experiences of the farmers who adopted this technology raises important questions regarding the reliability and validity of conventional ex-ante evaluations. But despite

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this spotty track record, these same ex-ante approaches are being mobilized to predict the impacts of soon-to-be-released second-generation GM crops.

The research presented in this paper offers a different evaluative approach by taking inspiration from farming systems research (FSR). FSR is an approach to agricultural development research that centers the farming system as the analytical starting point for testing and developing appropriate technologies for smallholder farmers. We operationalize this conceptual approach alongside a growing body of ex-post assessments of GM crop adoptions to inform a qualitative predictive analysis of three second-generation GM crops at various stages of experimentation: Water Efficient Maize for Africa (WEMA) in Kenya, disease-resistant cooking banana (matooke) in Uganda, and Bt cowpea in Burkina Faso. Our exploratory approach begins by asking the question: given what is known about a particular GM crop variety, how might it perform in target farming systems? In so doing, our approach shifts the analytical focus of the predictive analysis to the farming context with the aim of achieving the "wise anticipation" articulated by Sheila Jasanoff in the epigraph, and offering a more robust and accurate assessment of future patterns of technological change.

2. Conventional ex-ante evaluations of GM crops

Conventional ex-ante evaluations are predictive models designed to forecast the outcomes of new agricultural technologies and tools (including yet-to-be-commercialized varieties) by relying upon a suite of applied econometric techniques including discrete choice experiments, willingness-to-pay calculations, partial budget analysis, and economic surplus models, amongst others (Kpadé et al., 2017; Tarfasa et al., 2018). These are quantitative, experimental approaches employed primarily by agricultural economists and crop scientists built around hypothetical scenarios designed to assess the impact of new technologies on the status quo. While such

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predictive approaches can be employed to assess any new agricultural technology, here we focus on their application to GM crops – particularly the new generation of GM carbohydrate staples that are currently under development (Ainembabazi et al., 2015; Gbègbèlègbè et al., 2015). Contributions from Smale et al. (2009), Glover (2010), and Stone (2012), have analyzed the epistemological and methodological shortcomings of these conventional ex-ante approaches as they relate to GM crops. We summarize these findings as follows:

2.1. Poor data quality

Any predictive tool is only as good as the data upon which it is based, and there are multiple ways that poor data quality affects the accuracy of standard predictive tools. Conventional ex-ante evaluations of GM crops generally rely upon some combination of performance measures from experimental stations and early on-farm trials. Data gathered from each of these contexts has its own shortcomings.

New breeding technologies such as GM crops undergo trials for trait efficacy and performance on experimental research stations, supervised by teams of technicians, who are able to avail themselves of timely applications of inputs including fertilizers, pesticides, mulch, and water. Experimental stations thus tend to reflect ideal growing conditions where crops receive optimal amounts of inputs at the most advantageous moments in the growing cycle. These attentive and well-resourced environments differ dramatically from the highly variable socio-environmental conditions in which smallholder farmers operate, leading to field trial data that tend to overvalue actual benefits realized by farmers (Azadi et al., 2016; Glover et al., 2017). Nevertheless, ex-ante evaluations of second-generation GM crops continue to rely on experimental field trial data to predict farm-level outcomes (Ainembabazi et al., 2018; Wesseler et al., 2017).

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Early farm trials—carefully selected farmers who grow soon-to-be-commercialized varieties on their own plots—can also lead to an overestimation of benefits due to related forms of bias. These include selection bias (i.e., early adopters of GM crops constitute an unrepresentative group of high-performing farmers), cultivation bias (i.e., the special care or preferred locations afforded to GM crops do not reflect average growing conditions), and time-term bias (i.e., the tendency to measure short-term outcomes and expect that these will persist over the long-term) (Stone, 2012; Dowd-Uribe, 2017; Kranthi and Stone, 2020). Taken together, these biases make it difficult to attribute any productivity gains achieved by early adopters to the GM crop itself.

2.2. Problematic assumptions

Exacerbating poor data quality are problematic assumptions embedded in the models used to forecast farmer outcomes. These take many forms. The most persistent is that farmers are rational actors who make key agricultural decisions based on measurable differences in yield (Yirga et al., 2020; Gbègbèlègbè et al., 2015). This assumption ignores the considerable body of evidence demonstrating the importance that characteristics such as taste, color, texture, and other agronomic factors play in on-farm decision-making (Cleveland and Soleri, 2005; Schnurr et al., 2020), while underappreciating how GM trait diminishment undermines yield stability over time (Smale et al., 2009). Other assumptions about farmer behavior persist throughout conventional ex-ante evaluations: static adoption rates, how much area farmers will allot to new varieties, that farmers will follow recommended growing practices and plant refuges to slow pest resistance, and that farmers can afford and will properly apply the inputs needed to maximize yields (De Groote et al., 2011; Elbehri and MacDonald, 2004). Ex-ante evaluations also tend to rely on fixed prices and rates of production (which never occur in practice), assumptions regarding

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market behavior (e.g., increased yields will have no impacts on prices or labor), and presume that GM varieties will benefit all farmers equally, without accounting for different outcomes based on access to land, gender, age, land size, and education, among other factors (Wesseler et al., 2017).

Problematic data extrapolations are another related issue. For example, a series of recent studies from the International Food Policy Research Institute (IFPRI) employ a particular economic surplus model known as the Dynamic Research Evaluation for Management (DREAM) designed to estimate consumer and producer gains resulting from the introduction of a new agricultural technology. The aim of these predictive studies is to analyze potential gender differentiated welfare effects for second-generation GM crops in Ghana (Dzanku et al., 2018), Tanzania (Ruhinduka et al., 2020), and Uganda (Kikulwe et al., 2020). In each case, though, the absence of sex-disaggregated data forced researchers to extrapolate from national data sets including longitudinal household surveys and national level statistics. This imprecise extrapolation from existing data sets undermines the predictive utility of these models, a limitation that the authors themselves acknowledge where they qualify their results as "quite speculative as they are derived from data captured in surveys that are not designed to examine gender differences" (Dzanku et al., 2018, p.48).

2.3. Narrow scope

The third limitation associated with conventional ex-ante approaches stems from their narrow scope. In terms of traits, predictive models prioritize yield measurements, which ignores the critical role that local farming practices, knowledge, and conditions play in the success of any new crop (Glover, 2014). The farming context is not treated as an important variable to be analyzed, despite substantial evidence of credit systems, seed value chains, input markets, labor regimes and other contextual features determining who adopts and benefits from GM crops

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(Dowd-Uribe et al., 2014; Schnurr, 2019). Ex-ante evaluations often portray GM technologies as having "fixed functional characteristics that produce predictable effects. In such accounts, non-technical and non-economic factors are considered externalities, and they are often blamed when the results of technology transfer fall short of expectations" (Glover et al., 2017, p.15). This lack of analytical attention to space and place underestimates the importance of context and overestimates the transferability of GM crops across different settings.

In terms of adoption, ex-ante evaluations employ a narrow understanding of technology adoption as a passive rather than an active process. They reduce adoption to a binary choice—farmers either adopt a technology or they do not—which minimizes the role of farmer agency in shaping outcomes with new technologies. Ex-ante evaluations are unable to conceptualize adoption as a practice-oriented process of technological change, which requires broader categories of intended and unintended impacts documented over longer periods of time (Glover et al., 2019).

Finally, in terms of impacts, ex-ante approaches often obscure differential benefits by the reporting of results in averages; when differential impacts are identified, they are seldom foregrounded in the reporting of results (Glover, 2010; Stone, 2012; Luna and Dowd-Uribe, 2020). The result is an underappreciation for how intersectional categories of difference including gender, ethnicity, land size, land tenure arrangements, and previous experience with new technologies shape farm-level outcomes.

3. Farming Systems Research

Farming Systems Research (FSR) is a body of scholarship that seeks to assess the impacts of existing agricultural technologies on smallholder farmers and generate appropriate technologies

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to meet their needs. It accomplishes this by shifting the analytical focus of agricultural research to the complex ecological, economic, and social components that constitute the farming system (Whitfield et al., 2015; Darnhofer et al., 2012; Collinson, 1987). Defined by Collinson (2000, p.1) as "a diagnostic process; a basket of methods for researchers to elicit a better understanding of farm households, family decisions and decision-making processes", FSR emerged in the 1970s as an interdisciplinary counterpoint to conventional, top-down assessments of new agricultural technologies, largely in response to dissatisfaction with the crop development and dissemination systems that undergirded the Green Revolution era (Hart, 2000; Stroud and Kirkby, 2000).

In response, the 1980s saw natural and social scientists build a thriving farming systems praxis at international and national agricultural institutions across the Global South (Poats et al., 1986), with important advancements in sub-Saharan Africa (Bingen and Gibbon, 2012). FSR proponents sought to study "together with the farmers, the natural (i.e. technical) and socio-economic (i.e. human) environments in which farm households operate" (Norman, 1995, p.14). This was an explicit effort to make the farming household, as opposed to the research station, the appropriate site for interrogating whether and how a technology could be created and/or usefully adapted to smallholder farming systems (Gilbert, 1980). Parallel and contemporaneous to this approach, scholars forwarded ways of understanding farming as a set of performances that unfolded over time (Richards, 1985; see also Lev and Campbell, 1987), and how farming practices and decisions "are embedded in particular agroecological and sociocultural contexts that give rise to a plethora of changing conditions to which the farmers must make a series of rolling adjustments" (Thompson and Scoones, 1994, p.61; Sumberg, 2017).

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Over the years, FSR has evolved into a form of place-based agronomy that is "more concerned with understanding the risk of success or failure of a technology and how the technology fits for different farmers than with average responses" (Giller et al., 2017, p.156). FSR has also expanded to pay closer attention to the knowledge politics that underpin development-oriented agronomy, prompting critical reflection around which forms of knowledge matter, how particular interests shape the types of questions we ask, and the "broader political economic forces which shape the development and dissemination of new technologies" (Isgren et al., 2020, p.10. See also Taylor et al., 2021; Andersson and Giller, 2019). Most recently, FSR-inspired ex-post assessments of GM crops in the Global South have illuminated mismatches between GM crops and existing farming systems, the important role that institutional context plays in supporting the adoption of GM crops, differential impacts based on the level of capitalization of the farming household, and the political dimensions of knowledge production and technology development (e.g., Stone, 2011; Dowd-Uribe, 2014; Luna and Dowd-Uribe, 2020; Schnurr, 2019; Flachs, 2019; Leguizamón, 2020).

In this article, we draw from FSR scholarship to inform an exploratory analysis of soon-to-be-commercialized GM varieties in sub-Saharan Africa. Though FSR was originally envisioned as an approach to create new technologies that are farmer driven, we assert that FSR can inform the conceptual starting point and guide the analytical focus of predictive analyses of new agricultural technologies—in this case GM crop varieties—to address the needs of different types of smallholder farmers. FSR scholarship in general, and more specifically ex-post FSR-oriented assessments of GM crops, center several analytical insights which inform our predictive analysis, including, how new varieties (a) interact with and within existing farming systems, (b) perform differentially depending on a suite of demographic, agronomic, contextual, and

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ecological factors, (c) are adopted in reference to livelihood strategies and assessments of risk, and (d) are part of a broader political economic context driving their development and promotion (Isgren et al., 2020; Whitfield et al., 2015). An FSR-informed analytical approach is grounded in the understanding of the farm as a system that is diverse and constantly evolving, creating space for a predictive analysis that is both heterogeneous and reflexive, foregrounding farmer voices, and able to offer a diverse set of pathways forward based on localized preferences (Eldon et al., 2020; Darnhofer et al., 2012). FSR is interdisciplinary and can avail itself of a suite of methodological tools including ethnography, participant observation, interviews, transect walks, ranking exercises, and surveys, among others. In short, the entry point for FSR is the system itself. With the orientation and tools described above, the guiding question for our FSR-informed analysis is: given what is known about a particular GM variety, how might it perform within existing farming systems? We assert that such an FSR-inspired analytical approach serves as a counterpoint and complement to conventional ex-ante evaluative approaches, which may yield more accurate and policy-relevant findings for how to better orient GM variety development and dissemination.

Below we report the results of an exploratory predictive analysis informed by FSR scholarship of three second-generation GM crops. The case studies are built on significant long-term field work of local farming systems in which these crops will be released and promoted. This deep understanding of local farming systems is complemented by crop-oriented qualitative field research. Over the course of the past twelve years, we have conducted over 250 interviews (140 in Uganda and Kenya, 110 in Burkina Faso) with crop development directors and personnel, research scientists, agricultural extension agents, seed developers and distributors, regulators, and activists. This expert knowledge was supplemented by farm-based interviews

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with Kenyan maize farmers in Kiambu and Muranga counties (2017 & 2018), with Ugandan matooke farmers in Nakaseke, Wakiso, Luweero, and Buikwe districts (2014, 2015, 2016, 2017, 2018 & 2019), and with Burkinabè cowpea farmers in the administrative regions of Hauts Bassins (2009 & 2018), Cascades (2012, 2013, & 2018), Boucle de Mouhoun (2018), and Centre Ouest (2018). We paid particular attention to the insights that emerged from ex-post FSR scholarship on GM crop introductions in the Global South including institutional context, differential impacts, household labor and land access dynamics, and understandings of risk. In what follows, we mobilize this longitudinal, qualitative data to offer what we believe is a more robust predictive analysis of the potential impacts of these new second-generation GM crops on the farming communities they are designed to benefit.

4. Case Studies

4.1. Water Efficient Maize for Africa

The centuries-long effort to breed for drought-tolerance in African maize has been preoccupied with creating early maturing hybrids designed to thrive within the optimal breeding conditions and intensive management regime of the experimental station (McCann, 2005). In the late 1990s, the International Maize and Wheat Improvement Center (CIMMYT) embarked upon a new approach designed to breed maize across a wide range of stressed environments that resembled more realistic and representative scenarios experienced by farmers. This pivot provided the groundwork for several new maize breeding programs that aimed to enhance drought tolerance in Africa by breeding varieties for "mega-environments", which were then handed down to regional and local research centers so they could be adapted and released (Brooks et al., 2009).

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The *Water Efficient Maize for Africa* (WEMA) project, launched in 2008, sought to integrate the use of genetic modification within this spatially specific breeding approach. According to the Director of WEMA Partnerships at Monsanto, "genetic engineering offered the promise to add still greater drought tolerance to the already improved CIMMYT hybrids, resulting in even more substantial gains for drought-tolerant maize" (Edge et al., 2018, p.394). The WEMA project was initiated as a public-private partnership between CIMMYT, Monsanto (the technology purveyor), the African Agricultural Technology Foundation (AATF), and the Kenyan Agricultural and Livestock Research Organization (KARLO). WEMA secured over USD $100 million in funding over two phases from the Bill and Melinda Gates Foundation, the Warren Buffet Foundation, and USAID (African Centre for Biodiversity, 2015). In 2018, the Bill and Melinda Gates Foundation pumped an additional USD $24.6 million towards the eventual commercialization of WEMA maize (ISAAA, 2018).

In 2009 the AAFT—a not-for-profit, funded by the Gates Foundation, designed as a go-between connecting private biotechnology companies with humanitarian initiatives in the agricultural development sector—facilitated the royalty-free transfer of Monsanto's patented Cold Shock Protein B (MON87460), known commercially as DroughtGard. The CspB gene makes the plant less susceptible to yield loss during moderate drought conditions by improving the plant's ability to conserve soil moisture. The National Agricultural Research Systems (NARS) in five target countries—Kenya, Tanzania, Mozambique, South Africa, Uganda—were charged with adapting and distributing these genetically modified seeds, with later expansion planned for Ethiopia and Nigeria (Adewale, 2020; Tsegaye, 2020).

In 2011, the WEMA project made the consequential decision to integrate Monsanto's insect-resistant Bt gene alongside the drought-tolerance trait. Breeders justified this based on the

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dual prevalence of drought and stem/stock borer damage throughout the five target countries, arguing that stacking these two traits offers the best strategy for increasing smallholder productivity.[1] Stacking of the drought tolerant and insect resistant traits began in 2013, with preliminary accounts suggesting these GM versions outperformed traditional varieties during periods of acute drought (Conrow, 2016). The initial goal was to release the first GM variety in South Africa by 2017, but political delays in target countries—on-going GM ban in Kenya, stalled progress of the biosafety bill in Uganda—resulted in missed targets. The current goal is to commercialize GM WEMA maize in host countries by 2023 (Nanteza, 2018; Meeme, 2020).

Despite ongoing delays, preliminary assessments conducted by project partners suggest that WEMA's GM maize is achieving its goal of combined drought tolerance and insect resistance. Initial predictions suggest yield increases ranging from 20 to 40% due to these enhanced characteristics (Edge et al., 2018, Ruhinduka et al., 2020). Confined field trials supported this claim,[2] measuring yield gains up to 29% – though it is important to note these data were drawn from a sample size of only seven transgenic plants (Tefera et al., 2016). Socio-economic models predicted significant financial gains ranging from USD $117 million over ten years (Nagarajan et al., 2016), USD $200 million over five years (De Groote et al., 2011) to between USD $25 to 60 million annually (Mulaa et al., 2011). Country specific estimates offered net benefits ranging from USD $474 million in Kenya (Wesseler et al., 2017) to USD $848 million in Ethiopia (Yirga et al., 2020).

[1] Interview with Research Scientist 4, May 31, 2017; Interview with Research Scientist 2, July 21, 2015.

[2] Confined field trials are contained experiments used to evaluate the safety and field performance of new or improved crop varieties in an enclosed space designed to prevent the movement of genetic material.

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But a closer examination of the fit between WEMA maize and the farming systems it is designed to enhance suggest that the lofty estimates derived from conventional ex-ante evaluations will not be achieved in practice. Smallholder farmers in east and southern Africa tend to live on plots of land ranging from 0.2-3 hectares in size, with relatively limited access to credit and agricultural inputs (D'Alessandro et al., 2015). The potential for WEMA's GM maize to benefit smallholders will depend on how the technology and its components mesh within existing smallholder agricultural systems.

Fieldwork undertaken in Kenya exposes some of the incongruences between the experimental program elaborated here and the realities facing maize smallholder farming systems in east and southern Africa. The first major issue stems from the integration of the Bt gene, which requires adherence to a strict management regime to mitigate resistance amongst the target pest population. Take, for example, the implementation of refugia, a mandated planting of non-Bt maize adjacent to Bt maize, designed to promote the crossing of insects exposed to both types of maize in order to delay the inevitable build-up of Bt resistance amongst target insects. Recommended refuge configurations include block, perimeter, and split planter options, all of which are likely to be difficult for Kenyan farmers; studies among early adopters of Bt maize in South Africa found low levels of compliance amongst smallholders who regarded the prescribed refuges as labor intensive and time consuming (Kruger et al., 2009; Kruger et al., 2012).

Proponents tend to downplay the challenge of farmers maintaining this minimum refuge requirement. Some suggest that Kenya already has enough conventional maize varieties to meet the requirement of 20% non-Bt minimum refuge (Qaim, 2016, p.54). Others propose what's known as the "refuge in a bag" approach, which seeks to stave off resistance by including

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conventional seeds in a pre-mix layered on top of the GM seeds.[3] But neither mitigation strategy meets the core requirement for a spatially segregated refuge. Indeed, the "refuge in a bag" approach presents additional risk for accelerated resistance via potential pest movement from non-Bt to Bt plants and potential exposure of migrant larvae to a sublethal dose of Bt protein (Brévault et al., 2015; Erasmus et al., 2016).[4]

A second requirement that will prove problematic for smallholder farmers relates to the "biotechnology bundle" that will accompany WEMA seeds, a hodgepodge of required inputs relating to credit, fertilizer, and labor that is required for WEMA seeds to maximize the beneficial traits of drought-tolerance and insect resistance. As an official from AATF explained, "we will promote a package. You will not have benefit of that product without having that package. The package includes fertilizer, proper weeding, proper planting, timely planting, how many seeds you put per hole, what is the plant population you expect […] the seed performs as best as possible with all these in place, then you get your optimal production" (cited in Demers-Morris, 2015, p.64).

Existing research suggests this high-input production strategy that requires precise and timely management remain inaccessible to most smallholder maize farmers. Take fertilizer. The official recommendation is that farmers use 40kg of nitrogen per hectare for WEMA maize grown in lowland areas and 80kg of nitrogen per hectare for highland areas.[5] While the overall percentage of farmers using fertilizer is increasing in Kenya, few smallholder farmers are able to meet these ambitious targets. Fertilizer application for all crops across sub-Saharan Africa is

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[3] Interview with Research Scientist 2, May 31, 2016

[4] Interview with Research Scientist 5, June 27, 2017.

[5] Interview with Research Scientist 2, May 31, 2016

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around 13kg per hectare, well below the 94 kg per hectare across other developing countries (Minot and Benson, 2009). Application rates for maize are slightly higher in Kenya, ranging from 26 to 40 kg per hectare, with the lowest rates in the lowlands (Sheahan et al., 2013). WEMA maize will also require additional labor: recommendations for annual weedings, for instance, range from four by the coast, three in the lowlands, and between two and four in the highlands, yet previous research demonstrates that only 13% of smallholder maize farmers weeded twice a season (Muhunyu in Kalaitzandonakes et al., 2015). Additional weeding requirements will significantly increase labor costs; weeding a single hectare of maize by hand can take more than 50 hours of work (Kalaitzandonakes et al., 2015).

While WEMA seeds will be sold to farmers royalty-free, officials admit that the additional inputs in the form of fertilizer and extra labor for weeding will represent an additional cost that many farmers will struggle to afford.[6] But there are still no specifics on what, if any, credit will accompany WEMA's dissemination. The crucial link between credit availability and the adoption of improved seed has been documented extensively in the literature and was key to the high adoption rates of Bt cotton initially sustained in South Africa and Burkina Faso. Without sufficient and sustained access to credit it will be unlikely that smallholder farmers can afford the corollary inputs necessary for growing WEMA maize, meaning that the whole enterprise may collapse.

WEMA's GM maize continues the legacy of top-down breeding programs in that it builds in a reliance on inputs, credit, and labor that is largely unavailable to the project's intended beneficiaries – smallholder farmers in these target countries. The crucial question that needs to be asked is whether WEMA maize will be able to perform for farmers who are unable to meet

[6] Interview with Research Scientist 2, July 21, 2015

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the prescribed management regimes or afford the required input package. Without radical changes to the planned roll-out, the gap between the promises made by proponents and the realities of smallholder maize farmers seems too wide to overcome.

4.2. Disease-resistant cooking banana (matooke) in Uganda

Cooking banana, known locally as matooke, is a principal part of the Ugandan diet. Once harvested, the banana is peeled, cooked, and pounded into a bright yellow mash, which represents just over 30% of the country's daily caloric intake (NARO, no date). Matooke is ideally suited to the country's tropical climate and consumed widely in the central and southwestern regions of Uganda. The crop occupies 38% of Uganda's arable land (Nowakunda and Tushemereirwe, 2004) and is actively grown by more than 75% of Ugandan farmers (Sanya et al., 2017).

Matooke is propagated clonally by harvesting and transplanting suckers from existing trees, with significant production diversity in different regions. Farmers primarily source planting materials from their own fields (Kilwinger et al., 2017). In the central regions, matooke is grown predominantly for household consumption with excess production sold at the farmgate to traders who bring the crop to the capital, Kampala (Kalyebara et al., 2007). In the southwest, matooke tends to be grown on larger plantations and transported via lorry to markets in and around Kampala (Rietveld et al., 2016). The country's most recent agricultural census underlines the depth of this regional discrepancy: the southwest accounts for 68% of national production (with average yields of 6 tons per hectare), while the central region accounts for 23% of national production (with average yields of 3.3 tons per hectare) (Uganda Bureau of Statistics, 2010, p.54).

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Despite matooke's reputation as a low-maintenance crop, it remains vulnerable to a host of pests and diseases that cause widespread damage. One of the most devastating of these is Banana Bacterial Wilt (BBW), known locally as *kiwotoka*. Symptoms include rapid yellowing and wilting of the plant and leaves, as well as premature ripening of the bunch, discoloration of the pulp and internal vascular vessels, and secretions on the leaves (Tushemereirwe et al., 2003; 2004). Reports suggest that the disease costs farmers in central and eastern Africa upwards of USD $500 million annually due to crops losses and reduced productivity (Ligami, 2013).

BBW spreads through contaminated tools, plant materials, insect vectors, and infected soil. Measures such as removing male buds from infected plants; uprooting, burning, and burying the whole mat of affected plants; and disinfecting all farm tools that come into contact were promoted through educational campaigns to raise awareness and promote best practices (Tushemereirwe et al., 2006). These measures helped to halve the incidence rate in specific regions between 2005 and 2010. To reinforce these measures, the government adopted a more aggressive approach to ensure farmers were compliant. This approach was successful initially, but failure to consistently enforce these measure year-after-year allowed infection rates to resurge (Reeder et al., 2007; Carter et al., 2010; Shimwela et al., 2017).

The challenges associated with implementing cultural methods of control precipitated an investment in breeding for BBW-resistant varieties. But banana's long generation time and low levels of male and female fertility make breeding a difficult and lengthy process. Introducing new traits into popular varieties is exceptionally complicated (Dale, 2017). The challenges of conventional breeding alongside the difficulty in managing the disease via cultural methods led to calls for GM as the only solution to managing this pernicious disease: "only GM technology can save the banana regional eradication by banana bacterial wilt. There is no other way to

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reliably protect it" (Lynas in Magomba, 2013. See also Paarlberg in Meldolesi, 2011; Ronald, 2013).

In 2010, a collaboration was initiated between the International Institute of Tropical Agriculture (IITA), the National Agriculture Research Organization (NARO) and the AATF to genetically modify a banana resistant to BBW. Scientists zeroed in on two genes from green pepper that facilitated the sealing off of infected cells, the license for which was granted royalty free from a Taiwanese biotech company.[7] Confined field trials at NARO's Kawanda Agricultural Research Institute began in 2010, with the most resistant lines being replanted in subsequent years. In 2016, the head of the banana research program announced that they had attained proof of concept, with GM versions showing 100% resistance to BBW. Multi-locational trials were initiated soon after. Breeders aspire for a commercial release sometime in 2021 (Zawedde et al., 2018).

Across the great lakes region of Africa, ex-ante evaluations project the potential benefits of GM matooke could range anywhere from USD $20 million to $1.3 billion, depending on the severity of the disease (Ainembabazi et al., 2015, Wesseler et al., 2017). In Uganda, preliminary ex-ante evaluations using a real options approach indicate gains ranging from USD $176 million and USD $359 million annually, which would translate into an extra USD $38 per household (Kikulwe et al., 2008). A more recent analysis drawing on a mix of secondary data and local consultations also employs a real options model alongside economic surplus modelling using the IFPRI's DREAM software. Their findings suggest more modest gains of roughly USD $25 million per year across Uganda, of which $10.5 million would be accrued by producers (Kikulwe et al., 2020).

[7] Interview with Research Scientist 3, June 2, 2016

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But questions persist about the ability of a BBW-resistant variety to meet farmer needs. One concern relates to the parent variety into which the GM trait will be inserted. To increase the likelihood of adoption of GM banana, new varieties must fit within existing farming systems. Farmers have repeatedly been shown to reject new crop varieties when traits such as color, taste, and texture do not align with their preferences or needs (Jenkins et al., 2018). NARO's long-term plan is to transplant the GM trait for BBW resistance into an improved variety generated via conventional breeding, known as M9. M9 is the result of twenty years of systematic breeding that crossed Nakawere (a traditional variety) with the Calcutta 4 banana from India. The result is an "outstanding" improved variety that produces high yields and demonstrates strong tolerance to the common pests and diseases that damage matooke.[8] Breeders are confident that M9 will serve as the ideal host for the genetically modified trait of BBW resistance. But farmers are more skeptical. Farmers relay that M9 is more delicate and requires more labor and inputs than their preferred varieties. M9 is described by farmers as being too hard to mash and having a white color, which is undesirable for consumers. As one male farmer from the eastern region of Kamuli observes, "if it white then it not even matooke".[9] M9's recommended growing practices include more fertilizer, wider spacing, regular de-suckering, de-leafing and removal of male buds. Farmers may often lack the funds and labor to meet these requirements. As such, one of the major barriers to adoption of the GM banana might have more to do with an aversion to the parent variety into which the GM trait has been inserted, rather than an aversion to the process of genetic modification itself.

[8] Interview with Research Scientist 1, May 6, 2012

[9] Focus Group Discussion with Male Farmers, Kamuli District, June 18, 2013.

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Another issue relates to cost. While there will be no technology fee associated with the license to grow GM banana, the initial propagation will take place via tissue culture (TC), which will require farmers to purchase initial plantlets from nurseries. Smallholder farmers in Uganda typically purchase banana growing materials in the form of suckers via informal channels. A sucker from a neighbor can cost as little as 500 shillings (around USD 15 cents). TC plantlets from nurseries cost six to eight times as much. As a result, the penetration of tissue culture amongst smallholder farmers remains minimal: one recent study pegs TC penetration at below 20% (Flarian et al., 2018). Farmers explain this low rate of uptake based on TC's high cost and diminishing returns over time, which force them to buy new planting materials more often.[10] The high cost associated with the TC could slow down the dissemination process and present a barrier for poorer farmers to benefit from the commercialization of GM banana.

Another underexplored dimension of GM technology is how these improved varieties of banana impact women farmers. In the matooke growing regions in western Uganda, men retain primary control of key resources and decision-making (Rietveld et al., 2016), which ensures that men are more likely to capture benefits from the commercialization of GM banana. Addison and Schnurr (2016) paint a much more complex division of labor that varies considerably by region. In the central and eastern region, banana is considered to be a woman's crop, which means women are disproportionately responsible for labor inputs, in particular intensive activities such as harvesting. Men are more likely to retain control over decision-making and benefits, and due to limited commercialization are more likely to rely on women for these labor inputs. In the southwest, where banana is significantly more commercialized, farmers are more able to hire labor so the burden does not fall exclusively on female household members. As with the case of

[10] Focus Group Discussion with Female Farmers, Wakiso District, Dec 13, 2020

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WEMA maize, plans to address these gendered considerations upon the release of GM banana have yet to be made public.

4.3. Bt cowpea in Burkina Faso

Cowpea (*Vigna unguiculata*) is one of the most important crop species indigenous to the African continent. As known in French as niébé,[11] cowpea is a major protein source and the main legume in African lowlands (Ba et al., 2018). Traditionally intercropped with cereals and grown by men and women for household consumption, cowpea is increasingly being grown by men, and in single-crop fields, for sale in local and regional markets (Padmanabhan, 2007; Murdock et al., 2008).

Burkina Faso is the third largest producer of cowpea in Africa producing 603,966 tons, or 9% of Africa's total production in 2017. This is significant, but still considerably less than the two largest producers, Nigeria (45%) and Niger (30%) (FAOSTAT, 2019). Nonetheless, Burkina Faso plays an important role in regional cowpea production and trade, producing a surplus that is exported to neighboring countries (Bill and Melinda Gates Foundation, 2014; Kouman, 2018).

The Bt cowpea project in Nigeria, Ghana, and Burkina Faso is a significant moment in an almost 50-year-old modern breeding effort to transform the cowpea. Since the 1970s, crop scientists at the IITA in Nigeria have sought to breed cowpea varieties for improved resistance to pests, diseases, viruses, drought and heat tolerance, and yield (Murdock et al., 2008). One problematic area in these research efforts was breeding resistance to the legume pod borer (LPB) (*Maruca vitrata;* Syn *Maruca testulalis*). Decades of breeding focused on transferring genes conferring resistance from wild relatives into cowpea germplasm, but with little success (Adati et al., 2008). In this regard, transgenic technologies, and specifically the transfer of the Bt (*Bacilus*

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[11] The term niébé is derived from the Fulβe term ñebbe.

thuringiensis) gene is viewed as a major advancement (Baoua et al., 2011; Srinivasan et al., 2021).

The AATF negotiated a royalty free transfer of the Bt gene (*Cry1ab*) from Monsanto to be used in the production of Bt cowpea. The Bt cowpea parent crop was then transferred to national scientific research institutes in Ghana, Nigeria, and Burkina Faso, where it was crossed onto several cultivars. Ultimately, confined field trials focused on one common variety across the three countries, Songotra (IT97K-499-35), and two additional varieties in Burkina Faso, Niizwe (IT98 205-8) and Gourgou (TZ1-Gourgou). Two new varieties, each containing two *Cry* genes, are currently under experimentation and may be ready to commercialize as early as 2023. Pending biosafety approval, single *Cry* gene varieties will be ready to be reproduced in 2021, and broadly commercialized in Burkina Faso in 2022.[12] Nigeria had hoped to be ready to commercialize Bt cowpea in 2020, but these efforts stalled due to the COVID pandemic (Isaac, 2020).

Advocates claim that Bt cowpea will be advantageous for smallholder farmers by reducing the need for chemical pest control and increasing overall yields (Coulibaly et al., 2008, Dzanku et al., 2018). Recent ex-ante evaluations of Bt cowpea suggest high net returns for both producers and consumers. These anticipatory evaluations are confined to Burkina Faso's neighbors, but offer insight into projected gains and the underlying assumptions used to calculate them. Phillip and colleagues (2019) plugged data drawn from the Nigeria General Household Survey into a multi-region economic surplus model to assess potential outcomes. They project that Bt cowpea could produce benefits of up to USD $350 million, of which 70% would accrue to producers. Another assessment drawing on data collected from a choice experiment projected

[12] Interview with Research Scientist 6, August 5, 2018; Interview with Research Scientist 7, August 10, 2018.

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returns as high as USD $848 million per year assuming adoption of Bt cowpea in Benin, Niger, and northern Nigeria (Gbègbèlègbè et al., 2015). In neighboring Benin and Ghana, ex-ante evaluations predict respective benefits ranging from USD $50 million to USD $125 million per year (Dofonsou et al., 2007; Dzanku et al., 2018). These same studies utilize economic surplus modelling to predict the cost of a five-year regulatory delay, which is projected to lead to economic losses of up to 35% in Nigeria and anywhere from 29 to 39% in Ghana (Phillip et al., 2019; Dzanku et al., 2018). Another estimate suggests that a one-year delay in approval would cost Nigeria between USD $33 million and USD $46 million and result in between 100 and 3,000 lives lost (Wesseler et al., 2017, p.10)

Questions remain, though, around whether Bt cowpea will achieve these gains and, if so, what kind of farmer is most likely to receive these benefits. One key area of consideration is how variability in the geographic and temporal intensity of LPB affects the appropriateness and profitability of Bt cowpea for Burkinabè cowpea farmers. LPB is a pest throughout Burkina Faso, but it is most prevalent in the country's southwest, which is an area of low cowpea production (Ba et al., 2009). LPB is not a year-round resident in the north and east where cowpea production is more widespread (Traore, 2014). Moreover, LPB also exhibits high variability across growing seasons (Baoua et al., 2011). Given these geographic and temporal pest dynamics, Bt cowpea is most adapted for farmers in areas where cowpea currently isn't the major crop, and in years when LPB pest intensity is high. Projected yield gains will not be as high in areas and years where pest densities are lower.[13]

[13] This same point was made in the case of Niger. Gbègbèlègbè et al. (2015) surveyed cowpea growers in Benin, Niger, and Nigeria, and found that growers in more arid areas were less likely to pay a premium for Bt cowpea, since, pest densities are lower, and therefore, Bt cowpea was presumably less likely to be a profitable technology.

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Another factor complicating claims around reduced pesticide application is the LPB's temporal overlap with other cowpea pests, including aphids, thrips, beetles, and pod sucking bugs (Ba et al., 2018). Specifically, foliage and seed beetles as well as thrips have a significant and potentially greater potential to reduce cowpea yields than LPB (Singh, 1980). Thrips in particular are viewed as a more generalized threat to cowpea across Burkina Faso.[14] The vast majority of cowpea farmers use multiple insecticide applications to control pests. In a 2010 survey, INERA found that 96% of cowpea producers currently use insecticides to control for pests (INERA, 2015). Since the LPB pest overlaps at the same time in the growth cycle of the cowpea plant as thrips (Singh, 1980) and is controlled by the same pesticide (e.g., Decis), it is unclear whether Bt cowpea will significantly reduce pesticide applications in those areas and years where both pests are present.

Bt cowpea is primarily directed towards farmers who grow cowpea in monocultures, which, though growing in number, still comprise a minority of producers. The latest national data from 2012 show that over 90% of all cowpea is grown via intercropping (Dabat et al., 2012). But interviews with research scientists and cowpea farmers in multiple regions of Burkina Faso point to cowpea increasingly being grown in monocultures.[15] Farmers appear more prone to do so given the high market value for cowpea, and the increased availability of modern high yielding varieties specifically bred to be grown in monocultures. Cowpea breeders in Burkina Faso and elsewhere in Africa have focused on producing varieties in shorter growing cycles, with grain qualities geared towards commercial production (e.g. large grain size and white color) and importantly, that express bush-like growing properties. Intercropped cowpeas, by contrast,

[14] Interview with Research Scientist 7, August 10, 2018

[15] Interview with Research Scientist 7, August 10, 2018; Interview with Cowpea Farmer, August 4, 2018

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creep across the ground, quickly covering the soil, and climbing cereal stalks. The Bt gene in Burkina Faso was introgressed into three cowpea varieties, none of which creep, making them principally adapted for monocultures.[16]

Thus, Bt cowpea appears poised to accelerate a transition away from cereal-cowpea intercropping towards monocultures. In addition to being the most common way that cowpea is grown in Burkina Faso, intercropping cowpea with cereals has many documented advantages including reduced soil erosion, conserving humidity, and nitrogen fixation (Dabat et al., 2012; Zongo et al., 2016). Cowpea-cereal intercropping is also touted by many farmers and scientists as a means of reducing pest pressure and increasing the presence of natural enemies (Singh, 1990; Adati et al., 2008). Indeed, intercropping millet with cowpea outperforms monocultures of each under the partially shaded agroforestry conditions common throughout Burkina Faso (Osman et al., 2011).

Men and women have traditionally grown cowpeas intercropped with cereals, and the limited evidence available suggests that both also produce cowpea in monocultures; our field research identified organizations that worked specifically with women's groups to grow breeder improved varieties in monocultures for commercial sale.[17] Nonetheless, if Bt cowpea were to perform like other cash crops in the region, men will likely become its primary producers. The movement of formerly women's crops (e.g., rice) to men when commercialized for trade is well documented in West Africa (Carney and Watts, 1991; Carney, 1998). The transition from women

[16] One interviewed farmer also mentioned that modern bred varieties rot quickly in the fields – which is another reason why they don't work in intercropped field. One benefit of intercropped cowpeas is that they are harvested multiple times depending on maturity and labor availability (Interview with Cowpea Farmer A, August 4, 2018).

[17] Interview with Cowpea Farmer B, 3 August 2018 and Interview with Cowpea Farmer A, 4 August 2018.

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to men growing cowpeas with the adoption of modern varieties has already been documented in neighboring Ghana (Padmanabhan, 2007). Given that men tend to control access to land (Doss et al., 2015), and tend to capitalize on commercially grown crops, this trend towards monocropped Bt cowpea seems likely to benefit men more than women.

An important mediating factor in who adopts and benefits from Bt cowpea is seed price. High seed prices associated with transgenic crops have been shown to dissuade adoption by resource-poor farmers (Dowd-Uribe, 2014). Donor funding of Bt cowpea will allow it to be sold without a technology fee. Nonetheless, Bt cowpea seed will need to be multiplied, and is likely to fetch a higher price than other modern varieties (Dzanku et al., 2018). The national research institute and private seed companies are poised to serve as seed multipliers in Burkina Faso, and both will likely charge a higher price than what cowpea farmers are accustomed to paying. Indeed, our interviews with farmers and cowpea experts confirm that many, if not most, cowpea farmers are not accustomed to purchasing seeds. Given these current dynamics, those who are most likely to purchase Bt cowpea are those who currently purchase modern bred varieties, who constitute a small minority of cowpea producers.

In sum, Bt cowpea could result in profitability gains for moderate to well-capitalized farmers who grow cowpea in monospecific fields, in areas where LPB is a major pest, and, who use paid labor for pesticide applications. But for the majority of farmers who principally grow cowpea intercropped with cereals, who are not well-capitalized and/or who reside in areas where LPB is not a major pest, Bt cowpea is not likely to result in major profitability gains, and may not be adopted at all.

Finally, it is important to note that LPB is not the largest concern of cowpea growers. Though LPB is one of many pests that farmers must control, it is not their primary worry. Two

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prominent cowpea breeders in Burkina Faso conducted participatory rural appraisals (PRAs) of cowpea farmers to identify key production constraints in 2007-2008, and 2012.[18] Farmers in these studies did not identify LPB, or insect damage more broadly, as a major constraint. Rather, farmers prioritized soil degradation, access to inputs, equipment, improved seeds and markets, climatic issues, and *Striga* damage (Tignegre, 2010; Batieno, 2014). These studies cast doubt on whether Bt cowpea likely would have been prioritized had farmers and farming systems been more central in the development of this GM staple crop.

5. Conclusion: Centering Farming Systems

Conventional ex-ante evaluative approaches employ data gathering and extrapolation techniques that have systematically overestimated GM crop benefits for smallholder farmers in sub-Saharan Africa. Yet these same approaches are still being used to project benefits for a new portfolio of smallholder-oriented GM crops on the cusp of commercialization. We argue that evaluative approaches grounded in farming systems research are better positioned to anticipate the benefits and drawbacks associated with new GM varieties because they center farmers and the agroecological and political systems in which they operate. FSR rejects the poor data quality, problematic assumptions, and narrow scope that characterize conventional approaches. It also displaces the technology from manicured research spaces and focuses instead on the broader set of social and agroecological conditions into which a new GM crop will be introduced. Experimental field data and early farm trials are deprioritized in favor of a context-specific

[18] LPB was not mentioned as a major constraint in 5 of the 6 PRA villages. In the one village where it was mentioned, it was ranked 4th. The broader category of insect damage was ranked 4th, 6th, 6th, 9th, and 9th (Tinegre, 2010, p.44; Batieno, 2014, p.31).

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assessment of the GM crop's potential to succeed in particular places, for different types of farmers, and over time.

Farming systems research is not without its limitations. The results we present here do not employ statistical analysis, and do not conform to standardized norms around representativeness. More generally, FSR requires centering farmer concerns and deep knowledge of farming systems, making it more time consuming and logistically complex. Findings may not be replicable in other settings. Despite these shortcomings, we maintain that the evaluative approach taken here offers a more robust and potentially more accurate assessment of whether GM crops will flourish or fail among target beneficiaries. Reorienting the assessment of new varieties towards predictive methods that are grounded in the farming systems into which these varieties are intended to function should help to avoid the overly optimistic portrayals that the now twenty-year old empirical record of GM crops in sub-Saharan Africa have shown to be specious.

Our exploratory predictive analysis of three second-generation GM staple crops shines a light on crucial dynamics that remain obscured in conventional ex-ante evaluations: (1) differential impacts of new technologies, especially based on land size, capital intensity of the farming household, and gender, (2) extra costs associated with additional requirements in the form of fertilizer and labor, and (3) the 'fit' between the new technology and existing farming practices. A systems-based approach to the evaluation of new agricultural technologies underscores the importance of understanding the complex drivers of farmer decision-making, delineating the various political, economic, and social conditions that structure a particular farming system, and assessing the compatibility between a particular technology and the system into which it is being introduced.

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This emphasis on heterogenous farming systems reveals that the lofty projections of the examined GM crop varieties to improve yields and livelihoods are unlikely to be realized by many, if not most smallholder farmers. Variety selection and access are areas which demand critical attention. In all three evaluated crops, farmers express reluctance towards the parent varieties chosen as the vessel for the desired GM trait. This will hinder uptake. A further impediment to adoption is the relatively higher seed costs associated with the reproduction and sale of the GM varieties (despite the absence of a technology fee). The high cost of inputs required to achieve desired functionality and profitability will also impact adoption and performance.

In all cases, the farming context and supportive institutional structures needed for widespread adoption and optimal performance are not significant parts of the crop development and deployment strategy. Though ostensibly bred for all smallholder farmers, these crops are geared to farmers who already employ more capital-intensive farming strategies, or those who have the resources to transition towards these approaches. In most cases, these are men, despite the targeting of “women’s crops” such as matooke and cowpea.

Taken together, these findings raise the important question of what sustains these programs if the technologies they develop are not likely to benefit resource-poor smallholder farmers. We argue that current evaluative approaches play a crucial, if overlooked, role in sustaining the direction and nature of these experimental programs. As Jasanoff (2016) highlights, a restrictive and reductive approach to evaluations fuels a form of “trickle down innovation”, one in which “the technological achievements of the wealthy and well-resourced define the anticipatory horizons of the less privileged” (p.257). It is crucial to destabilize current predictive approaches and supplement these with alternative approaches that foreground the diversity of farmers and

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farming contexts. The FSR orientation mobilized here is one such intervention, which can refocus attention on distributive and contextual factors lost in conventional analyses, opening spaces for reimagining these programs to better serve their desired beneficiaries.

The conventional ex-ante predictive models buoying the commercialization of new GM varieties into Africa are symptomatic of broader issues with program conception and formation. Restrictive and narrow evaluation methods are indicative of a top-down research and development agenda that rhetorically foregrounds poor and marginalized smallholder farmers while producing technologies which benefit the most powerful and highly capitalized among them. As a result, the future of improved crop varieties looks very similar to its past: an assemblage of new technological possibilities developed by well-funded donors with little input or consultation on the part of those farmers who are the technology's intended beneficiaries.

We believe that researchers must urgently reorient protocols around the needs, desires, and challenges of smallholder farmers, and then develop systematic approaches to assessing the potential benefits of a full range of different interventions. Refocusing how the impacts of new GM technologies are assessed—e.g. supplementing conventional ex-ante evaluation with new analytical approaches that center the farming system—represents an incremental step towards achieving greater participation and accountability in crop development, and creating a more collaborative, systems-oriented agronomy that centers farmer desires and embraces Jasanoff's call for 'wise anticipation' of technology for agricultural development.

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