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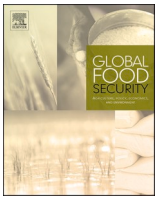

Socio-economic assessment and genetically engineered crops in Africa: Building knowledge for development?

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ABSTRACT

How could we know if agricultural development interventions make contributions to sustainable development goals (SDGs)? Genetically engineered (GE) crops are celebrated as a class of technological interventions that can realize multiple SDGs. But recent studies have revealed the gap between GE crop program goals and the approaches used to assess their impacts. Using four comprehensive reviews of GE crop socio-economic impacts, we identify common shortcomings across three themes: (a) scope, (b) approaches and (c) heterogeneity. We find that the evaluation sciences literature offers alternative assessment approaches that can enable evaluators to better assess impacts, and inform learning and decision-making. We recommend the use of methods that enable evaluations to look beyond the agronomic and productive effects of individual traits to understand wider socio-economic effects.

1. Introduction

Development interventions are justified based on their perceived contributions to sustainable development goals (SDGs). Donors, governments and policy makers seek evidence that the interventions they support achieve the desired social impact (Faure et al., 2020). This has led some research organizations to consider new evaluative approaches and methods to better measure progress towards SDGs. A broad takeaway from the evaluation sciences literature is that approaches applied in research evaluation should evolve - and specifically broaden in scope, disciplinary focus and tools - as the scientific community increasingly aims for social impact (Joly and Matt 2022). But are relevant organizations using adequate evaluative approaches to provide more comprehensive and sound evidence to gauge progress towards SDGs? If not, what can a deeper engagement with the evaluation sciences literature reveal to improve research impact evaluation?

This perspectives article examines one class of research interventions to achieve social impact - genetically engineered (GE) crops in Africa - and (1) argues that current evaluative approaches are insufficient to accurately gauge GE crop contributions to SDGs, and (2) offers suggestions for more comprehensive assessment approaches.

In line with definitions used by the US National Academy of Sciences, we use the term GE crops to capture the suite of modern molecular biological techniques beyond transgenesis alone and to include genome editing (NAS, 2016). GE crops have been singled out as key tools to achieve the first two SDGs of ending poverty and hunger, with a focus on

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Africa (Qaim 2010; Juma and Gordon 2014; Rock et al., 2023a). Moreover, GE crop research and development has received close to $400 million USD in public and philanthropic funding since 2001, with 172 crop varieties undergoing some form of development in 19 African countries (Dowd-Uribe et al., 2024).

Our examination draws from the collective experiences of the co-authors, who have expertise in GE crop variety and program assessments, and disciplinary expertise across a range of social and interdisciplinary sciences with a strong research focus in Africa. We draw specifically from reviews of both the GE crop assessment literature and the evaluation sciences literature to highlight shortcomings in existing evaluations, and make recommendations for more comprehensive evaluative approaches. This analysis was developed at an international workshop on the theme of GE crop assessment in Africa, held on June 7, 2023 in Montpellier, France.

2. Socio-economic assessments of GE crops in Africa

We draw from four widely cited comprehensive reviews (Klümper and Qaim, 2014; Zambrano et al., 2019; Fischer et al., 2015a; Catacora-Vargas et al., 2018) to characterize the GE crop socio-economic assessment literature in Africa. In brief, two main points emerge from these reviews: (1) a small but growing evidence base that signals positive benefits for farmers on some important economic indicators; but (2) this evidence base is insufficient to gauge the contribution of GE crops to SDGs. Klumper and Qaim (2014, pg. 1) reported "robust evidence of GE crop benefits," including yield and farm profit gains, and pesticide reductions for insect resistant (IR) and herbicide tolerant (HT) GE crops across all countries. Reviewing the Africa-specific assessment literature, Zambrano et al. (2019, pg. 13) highlighted that the evidence base is confined to a small number of African countries on a limited range of crops, but confirmed that "farmers have benefited from the adoption of [insect resistant] cotton and maize due to increases in both yield and net income."

Fischer et al. (2015a) and Catacora-Vargas et al. (2018) acknowledged these findings, but also highlighted important shortcomings with the evidence base. Fischer et al. (2015a, pg. 8611) noted that "very few studies take a comprehensive view of the social impacts associated with GE crops." More specifically, Fischer and colleagues concluded that, based on the available literature, very little can be deduced about GE crop impacts on poverty reduction since the vast number of studies had not used methods that enabled capturing diverse impacts across smallholder communities, or GE crop impacts beyond economic effects. Further, Catacora-Vargas et al. (2018, pg. 510) asserted that the assessment community must "acknowledg[e] the limitations of single-discipline economic, econometric and related methods" when attempting to measure a diversity of social impacts related to GE crop development and introductions. In the sub-sections below we draw from the selected reviews to identify the limitations of current assessment approaches.

2.1. Assessment shortcomings

2.1.1. Scope

Existing assessments of GE crops in Africa provide limited knowledge to gauge their contributions to SDGs. Zambrano et al. (2019) noted that the most common indicator used in the GE crop assessment literature is crop yield, followed by net income and seed cost. Though these indicators are important, they represent narrow snapshots often disjointed from a theory-informed and integrated approach to understand GE crops' potential contributions to SDGs. It is important to note that the supposed correspondence between yield and profitability increases, on one hand, and progress towards SDGs, on the other, remains implied and undeveloped. Several prominent SDGs, including poverty alleviation, food security and gender inequities, have received little or no direct attention in the assessment literature (Fischer et al., 2015a; Zambrano et al., 2019). More broadly, a suite of non-monetary indicators and outcomes at different scales, and often over longer periods of time–including, but not limited to, impacts on land tenure, land availability, seed systems, and autonomy–remain outside the purview of current assessment approaches (Catacora-Vargas et al., 2018).

2.1.2. Approach

The narrowness of widely used assessment approaches extends to a disproportionate focus on farm-level and singular effects (i.e. the effect of GE crop adoption on a single outcome variable), which provide a limited understanding of diverse and interactive impacts at different scales, and for diverse actors beyond farmers. Such a narrow approach to assessment undervalues and obscures the dynamic nature of agricultural technology adoption and impacts, and, notably, the crucial roles of non-farm actors.

Several biases inherent to measuring singular effects further erode the utility of current assessment approaches. Many GE crop evaluations use economic surplus models (ESM), which do not easily factor-in the effects of input markets, transaction costs, externalities and general equilibrium effects, hence creating bias in final impact estimations (Smale et al., 2009; Petsakos et al., 2018). These economic impact evaluation models are mostly predictive (ex-ante), are based on secondary data sources, and are based on assumptions rarely well-matched with the heterogeneous growing conditions, market failures and information gaps common to many African food systems (e.g., see Zambrano et al., 2022; Kikulwe et al., 2020). Moreover, much of the field data used in economic impact evaluation models likely suffer from selection and cultivation biases (Stone 2011, 2012), which have been shown to overestimate potential and actual benefits of GE crops in Africa (Luna and Dowd-Uribe 2020; Schnurr and Dowd-Uribe 2021).

A focus on farm-level and singular effects is mirrored by the non-inclusion of important farming system actors in the assessment process. This is particularly noteworthy given that inclusivity is an explicit goal of some GE crop projects (Beumer and de Roij 2023; Shilomboleni and Ismail 2023). The literature overwhelmingly shows that farmers, and specifically small-scale and marginalized farmers, have yet to be enabled to play a significant and empowered role as partners in the research, development, deployment and assessment of GE crops (Jacobson and Myhr, 2013; Schnurr et al., 2020; Schnurr and Dowd-Uribe 2021; Rock et al., 2023b; Dowd-Uribe 2023).

2.1.3. Heterogeneity

The narrow scope of current assessment approaches is compounded by the common practice of reporting outcomes in averages, which obscures how GE crop performance in the few measured indicators may vary for highly heterogeneous African smallholder farmers. This overemphasis on averages is particularly important given the linkages between differential impacts and the achievement of SDGs, such as poverty alleviation and food security. African smallholder farmers are incredibly diverse, of different ages, genders, and ethnic groups, with vastly different levels of capitalization, access to land and labor, household size and composition, and livelihood strategies, among other key factors (Tittonell et al., 2010; Chikowo et al., 2014; Fischer et al., 2015b). Assessment approaches that fail to include farmers that reflect this diversity, or examine differential impacts across a number of relevant axes of social difference, risk missing important impacts, and misrepresenting overall progress towards SDGs.

Differentiation of impacts can be understood temporally as well as spatially. Farmers may experience different outcomes due to variable growing conditions, or changing pest dynamics, which can vary seasonally according to demographic, economic, and especially climatic and related agro-ecological factors, such as fluctuating populations of insect pests and disease vectors. This makes snapshots of a single season, or even a few seasons, potentially highly unreliable (Fischer et al., 2015b). These limitations are seen in the extant assessment literature in a couple of ways. Data from field trials or early adoption years dominate

the corpus of assessments. Relatedly, one or few years of data are often used to understand ex-post impacts over time (Catacora-Vargas et al., 2018).

In short, though the current assessment literature examines some key socio-economic indicators, these alone are insufficient to comprehensively gauge the contribution of GE crops in Africa towards SDGs.

3. Improving socio-economic assessment

Here we turn to the evaluation sciences literature to identify insights and evaluative approaches that could address these shortcomings.

3.1. Process orientation

One argument to emerge from the evaluation sciences literature is a need to focus on process. Approaches that include systemic and process-oriented conceptualisations of impact show how a technology reaches its (intended and unintended) users via different pathways, through diverse types of encounters, at different points in time, through varied types of dissemination or translation channels, generating diverse impacts (Pawson and Tilley 1997; Mayne 2012). Process-oriented evaluative approaches address critical shortcomings in current assessment approaches, bringing a focus to farm and non-farm actors, temporal and spatial heterogeneity, and highlighting a diversity of impacts. Two classes of process-oriented approaches, process tracing (Bennett and Checkel 2014) and theory-informed evaluation (discussed in the next paragraph) have been used in other domains, but are significantly underutilized in agricultural research evaluation.

One process-oriented conceptual framework that has been adopted in agricultural research evaluation is the *Propositions- Encounters- Dispositions- Responses* (PEDR) framework proposed by Glover et al. (2019). In this framework, the concepts of technology transfer and adoption are replaced by a conception of technological change as a process that engages multiple actors, who interact in a reconfiguration of local techniques, relationships and institutional arrangements; a process which reorganizes practices and redistributes agency as existing practices are abandoned or adjusted. The PEDR framework was used to reinterpret the successful introduction of improved chickpea varieties in Andhra Pradesh, highlighting the importance of non-farm actors and processes at larger spatial and temporal scales with important implications for how to realize social impact (Glover et al., 2021).

3.2. Theory-informed and participatory approaches

Two additional arguments to emerge from the evaluation sciences literature are the need to adopt theory-informed (i.e. based on a theory of how change happens, or on a targeted social science theory) and participatory approaches to more comprehensively understand a diversity of impacts from a number of perspectives. When an intervention, such as the introduction of a GE crop, is conceived, it embodies a logic of how activities will lead to desirable outcomes and for whom. Theory-informed evaluations collect evidence of whether and how these outcomes were actually achieved, and whether they followed the intervention theory (Chen 1990; Mayne 2015). These methods elaborate and test the chain linking causes and effects, making explicit the assumptions about the underlying mechanisms that drive this chain of effects, and why and how agents react to the intervention, with what consequences (Joly et al., 2015).

In parallel, participatory approaches in evaluation engage stakeholders in designing, implementing, analyzing or using evaluation results, or any combination of these evaluation activities. Stakeholder involvement can help to generate evaluative questions that are insightful and well-targeted to analyze causal mechanisms or impacts of interest. The intensity of participatory engagement in these methods can vary, from collaborating with evaluators in charge of the evaluation process (collaboration), to sharing control over the evaluation process and decisions (participation), to being in control of the evaluation, with the evaluator being a critical companion to support rigor and adequacy of the process (empowerment) (Fetterman et al., 2013). Participatory approaches, which are particularly useful in answering the "which impacts for whom" question, can be easily paired with other approaches to answer the "how much impact for whom" question (Stern et al., 2012).

One evaluation approach that combines theory-informed evaluation and participation in the evaluation of agricultural research interventions is ImpresS ex-post (Faure et al., 2020). The evaluation of a participatory sorghum breeding program in Burkina Faso showcases how GE crop evaluation can benefit from applying this type of evaluation approach (vom Brocke et al., 2020). The case study focused on the contribution of research to a technological change process where participatory development of improved crop varieties and their dissemination were carried out with and by multiple stakeholders over 20 years. Thirty measurable impact indicators were identified in participatory workshops that involved 41 actors engaged in this process over time, then assessed through structured interviews with 100 farmers and semi-structured interviews or focus groups with 52 other actors including farmers, processors, input traders and institutional agents, as well as an analysis of secondary data on sorghum production and consumption. The identified outcomes included the establishment of a decentralized certified seed production scheme; the restructuring of the national seed sector and certified seed market; a stronger role for farmer unions in national legislation; the building of new interactions and collective learning processes; the reduction of the hunger gap and an increase in revenues at the household level. This approach provides a comprehensive overview of diverse impacts for multiple stakeholders at different scales.

3.3. Understanding trajectories and heterogeneity

An additional argument for going beyond linear and narrow impact evaluations is the need to evaluate heterogeneous outcomes generated for different agents over time. The PEDR and ImpresS approaches from the previous paragraphs tackle these elements, but here we focus on an example of multi-scale evaluations that directly address them. Outcome Trajectory Evaluation (OTE) identifies an overarching social science theory that first delineates the outcome trajectories for a cluster of desired outcomes. It then evaluates how an intervention contributes to the identified cluster of outcomes. Findings are then used to update the implied theory of change informing interventions (Douthwaite et al., 2023a). OTE assumes that an outcome is generated and sustained by dynamic interactions of actors, knowledge, institutions, and technologies. Outcome, in this context, is defined as the change in behavior, relationships, or practices of individual or collective agents. Douthwaite et al. (2023b) employ an OTE approach to examine how the Harvest Plus research program contributed to the establishment of national biofortification breeding programs. The evaluation identified three outcomes: a shift in norms; changes in capacity; and a strengthened base of support. HarvestPlus provided funding and capacity development to support national programs to work on biofortification breeding, which, over time, expanded to other actors of the seed systems. This, in turn, strengthened the support base for biofortification scaling, which was complemented by biofortification advocacy, and efforts to build institutions. In turn, this changed actors' perception of biofortification, who saw it as a solution to micronutrient malnutrition.

4. Toward comprehensive socio-economic assessment of GE crops

GE crops are seen as a key means to address grand challenges in Africa (Kates and Dasgupta 2007), and, in particular, alleviate poverty and improve food security amidst a changing climate (Fischer and Rock 2023). We have argued here that current GE crop assessment approaches do not deliver sufficient knowledge or insight to confidently gauge the contribution of GE crops towards those objectives. Conventional

assessment approaches suffer from an overly narrow scope, and discount heterogeneous effects over time for a diverse group of farmers and non-farm actors. Moreover, the starting point for these assessments generally takes a limited view of the diversity and complexity of social interactions, an understanding of which is needed to illuminate systemic impact pathways, and facilitate desired and sustained outcomes for heterogeneous actors.

The emerging evaluation approaches and methods outlined above are able to provide new insight into the multiple and diverse impacts of GE crops in Africa. They rely on identifying appropriate methods to answer diverse evaluation questions that go beyond the focus on how much economic impact GE crops generate for selected stakeholders. Challenges exist to the uptake of these assessment approaches. Agricultural research institutions have entrenched assessment logics, and there is a lack of training and awareness on the part of researchers and key personnel. Nonetheless, some agricultural researching institutions continue to develop and implement these and similar approaches for several non-GE crop interventions (Blundo-Canto et al., 2019; Leeuwis et al., 2018). Learning from these examples is crucial in guiding their consideration and application to GE crop projects, and other agricultural innovations that target SDGs in Africa.

This is a time of contentious debate about the proper direction and progress of efforts to build agricultural dynamism in Africa amidst a changing climate (Giller 2020; Wise 2020; Wudil et al., 2022). It is also a time of renewed calls to build the institutional capacity of national agricultural research systems (NARS) in Africa (Jayne et al., 2023). We argue that addressing SDGs via agricultural development requires institutional capacity building, not just in the life and natural sciences, but also the social and evaluative sciences. Building such capacities can help to enable the uptake of appropriate and comprehensive assessment frameworks to accompany and guide GE crops projects as well as other interventions for social impact. These frameworks can produce knowledge to inform key policy debates (Ely et al., 2014), provide timely and informative inputs to regulators (Binimelis and Myhr 2016), and inform the use and targeting of scarce resources to best achieve SDGs.

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CRediT authorship contribution statement

Brian Dowd-Uribe: Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Conceptualization. **Genowefa Blundo-Canto:** Writing – review & editing, Writing – original draft, Conceptualization. **Dominic Glover:** Writing – review & editing, Writing – original draft, Conceptualization. **Sélim Louafi:** Writing – review & editing, Writing – original draft, Conceptualization. **Helena Shilomboleni:** Writing – review & editing, Writing – original draft, Conceptualization. **Joeva Sean Rock:** Writing – review & editing, Writing – original draft, Conceptualization. **Enoch M. Kikulwe:** Writing – review & editing, Writing – original draft, Conceptualization. **Klara Fischer:** Writing – review & editing, Writing – original draft, Conceptualization. **Pierre-Benoît Joly:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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