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Experimenting with co-development: A qualitative study of gene drive research for malaria control in Mali

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ABSTRACT

We investigate how technology 'co-development' (between researchers, stakeholders and local communities) is framed in practice by those developing gene drive mosquitos for malaria eradication. Our case study focuses on UK and Mali-based researchers planning to undertake the first field trials in Mali of gene drive mosquitos for malaria control. While they and the wider gene drive research community are explicitly committed to the principle of co-development, how this is framed and practiced is not clear. Through qualitative analysis of 34 interviews complemented by observation and documentary research conducted in 2018, we identify and compare ten framings of co-development mobilised by UK and Malian researchers and stakeholders. For Malians, co-development reflected Mali's broader socio-political context and a desire for African scientific independence and leadership. It was mobilised to secure community and stakeholder support for gene drive mosquito field trials, through outreach, building local scientific capacity and developing those institutions (e.g. regulatory) necessary for field trials to go ahead. For UK participants, co-development was also concerned with scientific capacity-building, knowledge exchange between researchers, and stakeholder and community outreach to secure consent for field trials.

Overall, our findings suggest co-development is opening up previously expert-dominated spaces as researchers attempt to take responsibility for the societal implications of their work. However, its main function is as a project management tool to enable and instrumentally support technological development, field trials and eventual deployment. This function extends into areas which are traditionally the responsibility of the state, such as regulatory development, facilitated by Mali's fragile political and economic situation. Paradoxically, co-development simultaneously depoliticises gene drive, masking power relations and closing down substantive debate and agency. Characterised by extreme poverty, conflict and weak institutions, Mali may become a site for technological experimentation where there is little interrogation of gene drive or its governance.

1. Introduction

Malaria is a global health priority with immense social and economic costs (Sachs and Malaney, 2002). Gene drive mosquitos are an innovative approach to vector control being developed to fight malaria in Africa (Scudellari, 2019). A gene drive is a mechanism that spreads a desired gene and its phenotypic effect into a mosquito population (NASEM, 2016). By combining gene drive with the precision of CRISPR genome editing, scientists are able to modify the *Anopheles* mosquito genome and push modifications through the mosquito population to either suppress the population or modify its ability to carry the malaria parasite (Gantz and Bier, 2015). Gene drive supporters claim the potential benefits of this technology are significant, particularly for countries in the so-called 'Global South' where malaria is endemic and resources to fight the disease are severely limited (James and Tountas, 2018). They claim the technology could deliver a step change for vector control, possibly supressing or eradicating malaria and thereby fulfilling a key aim of global health efforts (Emerson et al., 2017).

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The gene drive mosquito for malaria control in Africa is expected to be the first gene drive organism in the world to be released into the wild. Led by Imperial College London and funded by the Bill and Melinda Gates Foundation (BMGF) and the Open Philanthropy Project, the research is being undertaken by a global consortium called 'Target Malaria' (www.targetmalaria.org). Target Malaria works with African partners in Uganda, Mali, Burkina Faso and Ghana and expects the first field trials of gene drive mosquitoes to take place in one of these counties within 4–9 years (Kahn, 2020). Target Malaria conducted precursor field trials of genetically modified (GM) mosquitoes in 2019 in Burkina Faso. This was designed to test the regulatory process and community relations for possible gene drive releases (Barry et al., 2020).

Despite its potential benefits, gene drive is controversial. The Civil Society Working Group on Gene Drives called unsuccessfully for a moratorium on gene drive research at the 13th and 14th Conferences of the Parties to the Convention on Biological Diversity in Mexico (2016) and Egypt (2018) (Callaway, 2016; Kahn, 2020). Gene drive developers have themselves raised concerns about its ecological risks and uncertainties given that gene drive mosquitoes are designed to spread throughout a population and persist in the environment (Esvelt and Gemmell, 2017). Just as significant are the challenges of obtaining stakeholder and community consent for trials and the governance challenges associated with potential transboundary movement of GM vectors across jurisdictional borders (George et al., 2019; Kofler et al., 2018).

The gene drive research community and its sponsors are aware of and highly sensitive to these issues, as well as concerns about 'Northern' technology developers pushing solutions to the Global South (Emerson et al., 2017) or promulgating various forms of 'colonial medicine' (Kahn, 2020: 6). Decades of research have stressed the need for technology development and related interventions in the Global South to be sensitive to situated historical, cultural, social, and political contexts, norms and practices (Pansera and Owen, 2018). The gene drive research community recognises that stakeholder, community and public engagement are key and the outcomes of such engagement are likely to be as important as the scientific outcomes (Akbari, 2015; Esvelt and Gemmell, 2017; NASEM, 2016; Thizy et al., 2019).

The concept of 'co-development' has emerged as a significant framing construct for societal engagement from within the gene drive community (Delborne et al., 2020; Hartley et al., 2019; James and Tountas, 2018). It stresses more inclusive forms of inter and trans-disciplinary collaboration in development pathways for gene drive mosquitoes. It is also supported by Africans who demand the involvement of African experts in decision-making around technological interventions, an involvement that has been limited to date (Kamwi, 2016). Indeed, the African Union's High-Level Panel on Emerging Technologies explicitly recommends a 'co-development' approach 'that emphasises collaboration between the partners in the teams, from research design to the creation of standard operating procedures' (AU and NEPAD, 2018: 2).

Co-development is a buzzword (Cornwall, 2007) and umbrella term (Rip and Voβ, 2013) that potentially aligns with various forms of participatory action research (e.g. Balestrini et al., 2017), 'upstream engagement' (Wilsdon and Willis, 2004) and 'inclusive innovation' (Fressoli et al., 2014; Pansera and Owen, 2018). All of these broadly speak to a 'co-productionist' perspective on science and society relations, where researchers work closely with those researched and/or affected by or interested in research processes, resulting in the inclusion of multiple perspectives into scientific work (Jasanoff, 2004). Such approaches have become increasingly popular for research between the Global South/North (John et al., 2016), including research on global health. They are appealing because they potentially offer an approach that is more culturally-sensitive, facilitating a two-way flow of knowledge and resources between North and South, and responding to past criticisms of externally-imposed, top-down and locally-insensitive approaches to technology introduction in the so called 'developing world' (e.g. Leach and Scoones, 2006; Nichter, 2008; Pansera and Owen, 2018). These approaches aim to re-frame techno-scientific knowledge production and develop technology in a socially robust manner (Nowotny et al., 2001; Fressoli et al., 2014).

Target Malaria views co-development as an essential element of its strategy for gene drive development (Hartley et al., 2019). It emphasises the importance of involving multiple experts, including those beyond the sciences, in shaping the technology so it becomes useful to those who need it (Ibid.). However, as a buzzword, co-development has interpretive flexibility and normative resonance (Cairns and Krzywoszynska, 2016), accompanied by little understanding of how it is framed or what it actually means in practice. Ledingham and Hartley (2020), in an analysis of international gene drive governance documents, suggest that whilst the language of co-development and co-production has potential for meaningful transformation, it often slips into reductive framings of collaboration driven by entrenched knowledge hierarchies. This, and other studies of related buzzwords such as 'inclusive innovation' strongly suggest that the meaning and impacts of such aspirational terms can only be understood by empirical studies of their translation and transduction in the field (Pansera and Owen, 2018; Doezma et al., 2020).

This study contributes to these efforts by investigating how co-development is framed in practice by UK and Mali-based research collaborators and stakeholders (hereafter 'participants') developing gene drive mosquitos to eradicate malaria in the context of Target Malaria. We adopt an interpretive approach, studying the discursive dynamics and associated power relations emerging from these practices, and noting the dominance of particular framings of co-development at the expense of others and the constitutive impacts these framings may be having in situated practice (Wesselink et al., 2013). Co-development is well suited to interpretive methodological approaches drawn from social sciences which can illuminate the 'how' and 'why' of co-development: how it is framed, achieved and enacted within and between actors and for what purposes and motivations (Bevir, 2006; Jasanoff, 2004; Yanow and Schwartz-Shea, 2006).

2. Method

2.1. Study setting and participant selection

Mali is one of the world's poorest countries, ranking 184 out of 189 countries in the UNDP Human Development Index (UNDP , 2019). It is the eighth-largest African country with a population of 15.9 million and has experienced extreme violence and political unrest since a coup in 2012 (Sieff, 2017). The recent coup, in 2020, resulted in significant international economic sanctions along with the African Union's suspension of Mali's membership (Birikorang and Salihu, 2020). This political instability and uncertainty along with the impact of the recent CoVID-19 pandemic has led to further economic hardship (Ibid.). Mali also has extreme gender inequality, ranking 156 out of 159 countries in the 2015 index (Sieff, 2017). Overarching and exacerbating these problems, as well as creating a host of distinct economic and health crises, is the fact that malaria is endemic in Mali, and resources to fight the disease are severely limited. Malaria is the primary cause of death, impacting significantly on children under the age of five (PMI, 2018). It is here that the world's first field trial of a gene drive organism is expected to take place (Swetlitz, 2017).

The Target Malaria research consortium involves collaborative partners in Africa, Europe and North America and is organised into science, regulatory affairs, project management and stakeholder engagement and communications teams. In Mali, Target Malaria partners with the Malaria Research and Training Center at the Université des Sciences, des Techniques et des Technologies de Bamako. The Center renovated an existing laboratory in Bamako to create a containment facility for safely receiving and working on transgenic mosquito strains imported from Europe (Quinlan et al., 2018). This insectary is situated

close to neighbouring communities and will house the research until the technology is ready for field trials. The Principal Investigator for Target Malaria in Mali works there alongside a Malian laboratory team, project manager and field team, who collaborate with their UK-based peers at Imperial College London and the University of Keele. The Malian engagement team is responsible for working with stakeholders at the local, national and regional level, including political authorities and regulators, and undertakes community engagement around the insectary in Bamako. On its website, Target Malaria provides short videos and materials about its activities in Mali (Target Malaria, 2020).

Research participants were selected through purposive sampling. Participants included seven Target Malaria scientists in Mali and the UK (molecular biologists, modellers, and entomologists), nine practitioners in Target Malaria's project management, regulatory affairs and stakeholder engagement and communications teams in Mali and the UK, and members of Target Malaria's ethics advisory board. We also interviewed seven gene drive scientists connected to but not employed though Target Malaria and eleven stakeholders including international and regional regulators and policy-makers, gene drive funders and supporters, ethics review board members, and civil society groups tracking the technology. Many participants have co-authored key international governing documents for gene drive (e.g. Akbari et al., 2015; AU/NEPAD, 2018; Emerson et al., 2017; James et al., 2018; Thizy et al., 2019). Gene drive for vector control is a relatively small research community which enabled us to achieve comprehensive coverage of the main actors in this field.

2.2. Data collection procedures

We used a mixed methods, qualitative approach including in-depth interviews, laboratory observation and documentary analysis to interrogate co-development from multiple sites and angles (Neely and Ponshunmugam, 2019). Our research was approved by ethics committees in Mali and the UK and all participants provided informed consent. We began by identifying key governance documents written by gene drive developers, international organisations, independent scientific bodies and research funders (e.g. James et al., 2018; NASEM, 2016). We used a discourse analysis approach (Fairclough, 2013) to identify recurrent themes and discursive formations to begin establishing how co-development is being framed and by which actors (Ledingham and Hartley, 2020). In 2018, two of the authors conducted short periods of observation and engagement in two of Target Malaria's laboratories – one-day in Mali and three-days in the UK. Through these, we gained an initial understanding of the relations and processes that connect and cut across these geographical sites, and of how participants view the science of gene drive.

We then conducted a total of 34 semi-structured interviews in 2018–16 conducted in French in Mali and 18 in English in the UK. Three of the UK interviews involved international actors. This interview format helped generate new insights, whilst diminishing the potential for the researcher to impose any rigid or pre-determined framework on the 'data' generation process (Galletta, 2013). These interviews provided an opportunity to understand and probe the framing of co-development in the participants' own words. A topic guide was first developed and interview questions designed around this to elicit knowledge flows and understandings and framings of co-development. The results of the documentary analysis and periods of observation and engagement shaped the design and refinement of interview questions. The interviews were recorded, verbatim transcribed and translated into French and English.

2.3. Interview data analysis

Data analysis proceeded through a sequential process of thematic analysis which is well-suited to interpretive approaches (Braun and Clarke, 2019). We held a collaborative data analysis workshop in October 2018. The workshop facilitated joint deliberation to bring different cultural, linguistic, disciplinary and professional perspectives to bear on the data and its interpretation (Cornish et al., 2013). Participants included Malian and UK researchers, one biologist not associated with gene drive and two engagement experts from Target Malaria, one who provides in-country support to the three African partners (Mali, Burkina Faso and Uganda) and one from the UK. During the workshop, we used thematic analysis to reflect on the interview data, challenge our assumptions, contextualize interview content and tease out key themes and interpretative stories (Braun and Clarke, 2019).

Following the workshop, the first and second authors read and coded all transcripts to construct an early set of themes. Coding was conducted in English. Drawing on this preliminary analysis and the results of the workshop, the two coders collaboratively developed a loose set of themes, removing duplicates and refining them. Each theme was discussed by both coders and entered into a shared 'living' document. Collaborative coding took place in a shared room where the coders could explore and reflect on the data through line-by-line coding in the shared

Table 1
Framings of co-development for gene drive research and development evoked by participants in Mali and the UK. The framings are ranked in order of prevalence (i.e. the number of participants that mentioned the framing) for each country. Framings mentioned by less than four participants were excluded.

Framings of co-development		
Framing	Mali	UK
Securing acceptance through engagement with communities and publics	**Rank: 1** M1-4,10,12–13,16: Total: **12**	**Rank: 6** U1-2,7,9,12,15,17: Total: **7**
Sharing information with stakeholders and the community through outreach	**Rank: 2** M2-5,7–10,12-13,15: Total: **11**	**Rank: 3** U1-6,8–10,12,16–18: Total: **13**
Creating new institutions and practices (and connections)	**Rank: 3** M1-3,6–10,13: Total: **9**	**Rank: 5** U1-4,7–10,13,15: Total: **10**
Developing scientific capacity in scientists, regulators and local communities	**Rank: 4** M1-2,5–7,10,12,16: Total: **8**	**Rank: 1** U1-3,5–11,14-16,18: Total: **14**
Furthering African independence and building African pride	**Rank: 5** M4-7,9–10,13: Total: **7**	Mentioned by less than 4 UK participants
Identifying and including a broad range of actors	**Rank: 6** M1-2,7,10,15–16 Total: **6**	**Rank: 4** U1,4–5,7-14,16: Total: **12**
Securing acceptance through engagement with stakeholders and politicians	**Rank: 7** M2-4,6,9: Total: **5**	Mentioned by less than 4 UK participants
Working together toward a shared goal	**Rank: 8** M2,4,9–10: Total: **4**	**Rank: 7** U1,6,8–10,16: Total: **6**
Drawing on and sharing multiple types of knowledge (two-way flow) within the project team	Mentioned by less than 4 Mali participants	**Rank: 2** U1-2,4–10,13-17: Total: **14**
Recognising the needs of stakeholders and communities and responding to their concerns	Mentioned by less than 4 Mali participants	**Rank: 8** U1-4,7: Total: **5**

living document to allow for a richer reading of the data with Malian transcripts first, and then UK transcripts (Ibid.). This thematic analysis was iterative and reflexive, allowing codes to develop and higher level themes to evolve. Once coding was complete, the first author précised the themes from the living document into higher level framings, drawing on data to illuminate the themes with the use of non-attributable quotes in order to protect participants' anonymity (see Table 1 and section 3). The analysis was checked by all remaining authors to ensure accurate interpretation (Ibid.).

3. Results

Ten framings for co-development were evoked across our Malian and UK participants. These are shown in Table 1 and discussed below in detail, first by country and then across countries.

3.1. Malian framings of co-development

3.1.1. Securing acceptance through engagement with communities and publics

Malian participants' most prevalent framing of co-development was as a means to *secure community and public acceptance* for Target Malaria's gene drive mosquitoes. Participants described the importance of gaining acceptance from 'communities', 'public', 'civil society', 'the population', 'individuals', 'wider community' and 'interested parties'. Community engagement for acceptance was however mainly focused on 'interested parties and communities around the insectary' in Bamako. Securing acceptance was seen as both the goal and practice of co-development. It involved passing information about the technology to communities and publics in order to obtain a form of agreement from the community to proceed with the research and possible trials. Participants used words such as 'explain', 'inform', 'consult', 'communicate', 'involve', 'participate' to describe the flow of information *to* communities. In this framing, engagement was motivated instrumentally to gain community support and consent. Participants described this support using words such as 'commitment', 'support', 'agreement', 'understanding', 'acceptance', 'authorisation', 'getting people behind the project', 'appreciating it', and gaining 'a social license'.

Acceptance was also described as a means of 'democratising decisions', since people had a 'right to ask'. Outcomes of acceptance were measured in a variety of ways. Participants described securing acceptance as means of 'achieving success', as 'key to success and good results', and when people are 'educated', 'believe in it', or 'grasp the benefits' of gene drive. This could take the form of a 'written document with the signature of the representative of the neighbourhood and representatives from the faculty'.

3.1.2. Sharing information with stakeholders and the community through outreach

Linked to securing acceptance was *sharing information* with stakeholders and the community through outreach. Participants described outreach in terms of 'explaining', 'informing', 'transmitting', 'making scientific language accessible to the community' and helping Malians 'memorise information'. It was seen as essential 'people understand the advantages' of what Target Malaria is doing. Outreach was viewed as having a role in educating communities and ensuring transparency. However, the information shared with local communities was noted as being limited. At the time our interviews took place, the engagement work that had taken place had not yet mentioned or discussed gene drive mosquitoes. Instead, conversations with communities were limited to explaining the causes of malaria and the role of mosquitoes. One Malian participant said: 'As soon as we have the authorisation to carry out the project we will tell people'. There was a concern that the direct translation of gene drive into French was more akin to 'gene force', which was considered to be potentially inflammatory and might hinder public acceptance.

Participants saw the sharing of information as taking different forms, including the use of theatre, images, posters, new experiments such as Café Scientifique and traditional communicators. Communicators were noted to be active in taking community members to 'visit the labs and insectary', holding informational meetings and making home visits. There were worries about the 'potential for misunderstanding of the message' and a recognition that gene drive was difficult to understand for non-scientists. There was a perceived need for social sciences to facilitate and support education and a belief that natural scientists need to learn how to communicate about gene drive. Outreach was seen as helping to secure acceptance for gene drive and to 'ensure understanding', 'calm concerns and fears', 'keep up the reputation and identity of Target Malaria', 'sell gene drive', 'avoid scandal', 'reassure', and 'reinforce the message'.

3.1.3. Creating new institutions, practices and connections

In the third most prevalent framing, co-development was seen as a means to support the co-creation of *local and national institutions, practices and connections* essential for successful technological development and deployment. Co-development in itself was seen as an innovation that African countries needed to embrace. Participants described a broad range of institutions, practices and connections that could be built through a process of 'co-creation' between researchers, communicators, stakeholders and communities.

Examples of new practices included 'opening up the insectary for the first time' to local communities (the insectary had been operating in Bamako for many years) and 'trying Café Scientifique'. Examples of new institutions were the establishment of a local governance committee to deal with complaints, and a committee of stakeholders and researchers seeking to create a national framework for consultation and debate over the use of gene drive in Mali. Some participants recognised that gene drive use might have wider consequences, such as behavioural changes in the use of mosquito nets. They argued that new 'political' institutions were needed in response, such as a panel to monitor the technology, a new national regulatory agency, and possibly new legislation. Participants noted the African Union Development Agency (AUDA) had been given a mandate for gene drive across Africa by various heads of state and the African Union and that regulators had attended training courses on gene drive and visited Brazil to learn about Oxitec's GM mosquito releases for Dengue control. These connections were seen as important, with a recognised need to learn from other countries and the need for academic networks and co-publishing of academic papers.

3.1.4. Developing scientific capacity in scientists, regulators and local communities

Co-development as *developing scientific capacity* was the fourth framing. Capacity building was seen as important for local scientists to 'master' the technology and enable 'this kind of technology to thrive in Africa'. This was linked to a desire to *further African independence* (see 3.1.5.). Some participants noted that African scientists can be portrayed as 'just technicians' to 'execute' the science that is controlled by 'the West'. Capacity building they hoped would enable African scientists 'to make gene drive mosquitoes from A to Z'. Capacity building for African scientists had to date involved visiting Target Malaria laboratories in Italy to 'see how they work, to be inspired by their work, to discuss experiments'. There was a sense that capacity building could ensure a legacy was left when Target Malaria ceased to exist and provide lasting institutions, structures and endogenous capacities for science.

Developing scientific capacity was viewed as key to building local institutions to educate people about science, and encourage 'a collaboration that mutually benefits everyone' between regulators and communities. Malians 'will need to approve this technology to be used' and scientific capacity helps to prepare the ground for decision-making. Local communities and villagers were described as not being 'empty-headed, they have lots of knowledge, knowledge that can be strengthened through co-development 'like a continuous training process'. In

some cases capacity building was seen as essential for 'training' people so they don't 'block' the technology i.e. securing acceptance (see above).

3.1.5. Furthering African independence and building African pride

A fifth framing that emerged from our Malian participants, was co-development to further *African independence and foster pride*. Participants pointed to the lack of development in Malian agriculture and genomics and felt they had 'missed the digital revolution' and could not afford to miss the genetics revolution. They also recognised the untapped potential of Malians, characterised as 'extremely intelligent and qualified, but don't have a sector which pushes people'. Establishment of internationally-recognised gene drive research in Mali was seen as an opportunity to 'regroup' and 'work together' to capitalise on existing strengths in science, create new jobs, build an emerging sector, attract large business and be an example for other countries. There was a sense that Malian scientists could lead the world in gene drive science and this is 'really the first time that Africa is leading the way' which created a 'sense of pride for Africa'.

Participants saw co-development as a way to break with neo-colonialism and past technologies 'which were imported, which came to us from overseas, which caused problems after they arrived'. Participants made clear: 'We don't want other people to impose gene drive, it's we who must adapt to this technology on our own in order that we develop as an African nation'. Co-development in this context meant 'it's us who are working on the development of the technology … a local development which is not imposed, and which is unique to Africans'.

3.1.6. Identifying and including a broad range of actors

Identifying and including a broad range of actors was a less prominent framing of co-development. Co-development of gene drive research had to get people 'involved' to 'show the people of our country this project'. There was a sense that 'it's not only scientists who are going to be affected by this new project so we need other people to get involved'. Malian stakeholders with perceived relevant expertise included ministries, national agencies, government departments, mayors, governors, political and traditional leaders, civil society, ethics committees, scientists, environmentalists, public doctors, vets, and agroforestry experts. This aligned with the previous framings around 'building scientific capacity' and 'creating institutions'.

3.1.7. Securing acceptance through engagement with stakeholders and politicians

A seventh minor framing was *securing acceptance through engagement with stakeholders and politicians* (in addition to local communities above). Emphasis was placed on engaging with political decision-makers, political leadership regulatory experts, and civil society. The success of the project was measured by 'the support of the stakeholders and that they understand the project'.

3.1.8. Working together toward a shared goal

Finally, the eighth framing was *working together toward a shared goal*. Malian participants saw co-development as a way to achieve the shared goal of eliminating malaria and this required 'cooperation', 'making use of all of our skills' and was 'something we do together'.

3.1.9. Overall narrative

For Malians, co-development reflected the broader social and political context of gene drive mosquito development in their country. Co-development was portrayed as being primarily concerned with securing community and stakeholder acceptance and support for gene drive mosquitoes under difficult social and political circumstances and weak institutions. In order to support this, engagement, education and outreach with communities are configured in largely linear, unidirectional and instrumental ways, explaining the project to gain support. As important was co-development as a means to build scientific capacity and co-create those institutions and practices necessary for successful technological development and deployment. This played into a broader ambition to build scientific independence and lead the way, as a source of national and African pride.

3.2. UK framings of co-development

3.2.1. Developing scientific capacity in scientists, regulators and local communities

UK participants viewed scientific capacity building as the most important framing for co-development, which in contrast ranked fourth for Malian participants. They viewed this as a two way process of 'knowledge exchange' between Mali and the UK, driven by the needs of the project and a longer term vision to sustain the technology. They recognised that while 'gene drive happens in the Global North' this 'is likely to change over time, because African scientists are themselves interested in being able to develop the technology there'. It was viewed as a way of 'empowering' Malian counterparts to 'contribute meaningfully' and getting them 'up to speed' in molecular biology rather than 'narrating them from behind'. This, they suggested, could be achieved by maximising opportunities for Malian scientists, building infrastructure, institutions and training and mentoring which involves the movement of project team members between Mali and the UK. Capacity building was viewed however as being broader than science. It also focused on developing expertise in engagement and regulatory science, communications, IT and English language skills. There was a recognised need to build capacity in Malian communicators – for instance, by learning local dialects. The UK side of the project was seen as having a responsibility to 'arm' Malians through capacity building 'otherwise they can't defend it and they can't promote it'. There was also a sense that Malians would be the 'face of the technology'. References to African independence, so prominent in the Malian interviews, did not feature within this group.

3.2.2. Sharing multiple types of knowledge within the project team

The second most prevalent framing of co-development for UK participants was *drawing on and sharing knowledge within the project team*. Malian participants did not mention this framing. There was a recognition by UK participants that each member of Target Malaria could not work alone, so co-development was described as 'teamwork', 'developing together', 'two-way' flow of knowledge, and 'ongoing dialogue between two people of different expertise or the same expertise' within the consortium. Knowledge was to be exchanged between Global South partners, between Global South/North partners and between project teams, for example between the Entomology and Regulatory Affairs Teams. Co-development involved 'looking at the value of each party and what they can bring to the consortium'. Mechanisms and practices of knowledge exchange included researcher exchanges between sites, meetings, briefings, presentations, blogs and posters.

UK participants valued Malian research colleagues for their knowledge of the local context, without which it 'would be impossible to know how to properly implement' gene drive and would likely result in the project being 'ignored'. Malian knowledge was seen as being 'embedded' in local cultures and communities and 'critical to confronting' challenges on the ground, understanding 'the local vicinity' and 'getting the research right'. Malian researchers 'know the area' and how to approach 'the villagers' 'stakeholders' and 'local agencies', 'convey information', 'get permission' and 'keep key stakeholders on board with the project'. This context was particularly important for field trial preparations because 'when you go into field trials, it's not just the expertise specific to the disease or the mosquitoes, its sociocultural understanding of what's going on and how best things might be approached'.

3.2.3. Sharing information with stakeholders and the community through outreach

Third, co-development was framed in terms of *sharing information*

with stakeholders and the community, a theme that also strongly emerged from our Malian participants. This form of outreach involved communicating almost exclusively with Africans in the form of one-to-one meetings, meetings with men, women, youth, chiefs, Imams, authorities, open days at the insectary and videos for local communities. The UK Communications Team trained African Communications Teams to share information with 'the same agreed messaging', 'in a simple language that [communities] can understand and process' and to train community people and leaders to do outreach. For example, one participant drew attention to: 'a woman outside the insectary in Bobo-Dioulasso in Burkina that makes the chapatis on the side of the road, and when she was interviewed, she explained exactly what was happening inside the insectary. She said that if she heard any mistruths about the project she would be taking that person directly to the insectary so that they could see exactly what was happening and to set them straight.'

There was a strong sense that Target Malaria needed to be 'transparent', 'answer questions', 'shift the perception of the problem', 'frame it in a way that will help us', communicate 'the importance of it' and 'manage expectations'. At the same time, participants believed this outreach would enable Africans to 'have an informed opinion of the technology' in preparation for decisions about the technology's use. Outreach was driven in part by previous experience in agricultural biotechnology, anti-GM action in Burkina Faso, concerns the 'project is being funded by Westerners', and by the need to get consent for an application for contained use of the mosquitoes from communities around the insectary.

Some UK participants recognised a tension between 'explaining yourself to the public', 'advocacy for the technology' and communication that might be perceived as being 'conflated with marketing and public relations'. UK participants not affiliated with Target Malaria raised concerns about a potential conflict of interest, given that the very existence of Target Malaria is predicated on gene drive technology being used. Concerns were also raised about whether information shared with communities explicitly mentioned gene drive rather than focusing exclusively on malaria and mosquitoes (See section 3.1.2. Above).

3.2.4. Identifying and including a broad range of actors

Identifying and engaging relevant actors ranked fourth in UK framings of co-development. UK participants outlined a 'strategy to engage all stakeholders about these technologies' including 'governments, other researchers, research scientists, opponents, villagers, with everybody we can'. The majority of actors identified by them were Malian. Expert actors were broadly interpreted to include medical entomologists, molecular biologists, social scientists, ethicists, sociologists, economists, legal scholars, risk evaluators, regulatory scientists, ecologists, mosquito population geneticists, mosquito vector control, malaria epidemiologists, agricultural scientists, people who can catch mosquitoes or deal with logistics, quality control and engagement, communications, mathematical modelling, statistical analysis, trial design, and project management. Stakeholders included gene drive supporters and opponents, governments, the Malian President, all the major international agencies (particularly WHO), funders from the USA, industry, and the Malian Minister of Health. Some civil society stakeholders operating at the international level (e.g. GeneWatch and the Third World Network) had been identified and invited to engage with Target Malaria but declined the invitation. Locally, actors included villagers and communities, particularly around the insectary in Bamako.

3.2.5. Creating new institutions and practices

Fifth, UK participants pointed to the importance of *creating new institutions and practices*. The purpose of this was largely to secure community consent and develop risk-based regulation, but less instrumental motivations were also mentioned. For example, co-development was noted as a new way of working, recognising the need for the project to be 'led by local researchers as well', whereas previous projects might have practiced 'learning from the Africans and then telling them what to do'. Key to co-development was establishing new community partnerships in order to give communities a 'voice'. New engagement practices included theatre forums and plays focused on sterile male mosquitoes and malaria, events with local musicians, quizzes, employing villagers to help the project with capturing mosquitoes and holding open days at the insectary for the first time. Learning about local culture, the 'impact of poverty' and 'being able to work with villagers and local stakeholders' was seen as critical for the UK participants. The UK engagement team worked with the Malian team to change the way Malian researchers learn and communicate with Malian policy-makers to establish new regulations for gene drive mosquitoes. Participants also saw Target Malaria as developing or facilitating new ways of conducting risk assessment, incorporating social and economic risk assessment and generally taking a 'risk averse' approach to assessment.

These new institutions and practices were aimed at 'developing the processes to support' [the project]. For example, the UK team provided Malians with 'people who had actual product development and regulatory expertise' to help them 'pursue product development'. Participants felt they were 'setting standards for the next projects'. Some participants cautioned against the need for new regulations which they felt might suggest gene drive was somehow 'unique'. The development of new regulations also led some participants to see conflicts of interest: 'We are the ones who have to be regulated but, at the same time, we train those who regulate it'.

3.2.6. Securing acceptance through engagement with communities and publics

Securing acceptance through engagement with communities and publics was the most prevalent framing for Malian participants but ranked sixth for UK participants. Acceptance was seen as essential for Target Malaria to operate in Mali and essential before field trails could take place: 'if the communities are not ready and accepting, we won't move'. UK participants observed a tension between 'engaging for acceptance and engaging for co-development'. This tension was also observed by UK participants outside the project: 'What I see is a technology developer who's very excited about a very powerful tool realising they need a certain level of social licence and thereby doing activities that will give them the impression of social licence, I don't think it's co-production'. Co-development was seen a means to secure acceptance by navigating opposition: 'We are so responsible in what we're doing … that it's difficult to … criticise'. Gene drive mosquitoes may become 'a very hot political issue' and it would be better to have these issues addressed 'by scientists from the community that's concerned, rather the people coming from outside'.

3.2.7. Working together toward a shared goal

The seventh framing to emerge from the data was *working together toward a shared goal,* where the goal is product development. Emphasis was placed on 'sharing' and 'thinking about the bigger picture' as well as 'buying in and believing in' the technology. Target Malaria's first release of GM mosquitoes in Burkina Faso was described as being 'created altogether'. Input from all partners, particularly Malian partners was seen as critical 'to make a product that works at the end'.

3.2.8. Recognising the needs of stakeholders and communities and responding to their concerns

Finally, the eighth framing emerging from the UK participants was *recognising the needs of stakeholders and communities and responding to their concerns*. This involved understanding 'concerns and expectations, what people want, what people are afraid of, what they would want to see tested'. It allows 'all parties to move in a sense of one another' and brings understanding of 'villages' cultural concerns and restrictions and how to respect those'. This framing was UK-specific and did not appear in the Malian framings.

3.2.9. Overall narrative

For UK participants, co-development appears to reflect awareness of the need to understand and work with the local context for gene drive mosquito development, preparing for field trials and future deployment. Co-development is largely viewed as a mechanism to engage with national and local stakeholders to secure consent, and build those institutions (e.g. regulatory mechanisms) necessary for these trials to go ahead (although there were some counterviews). As with the Malian narrative, the strategy for this includes an educating and outreach mission, sharing information, building scientific and regulatory capacity, forming local alliances and international networks. It leverages a narrative of promoting capacity building and is underpinned by an empathy and ambition to make research more inclusive.

4. Discussion

Co-development potentially offers an approach to gene drive research and development in the Global South that is inclusive, socially-robust and culturally-sensitive (Nowotny et al., 2001; Fressoli et al., 2014). By including and responding to a broad range of actors it can be transformative, re-balancing unequal power relations and knowledge hierarchies, through various forms of capacity building, engagement and co-production (Ledingham and Hartley, 2020). Scholars of stakeholder and public engagement have asserted that this can be motivated by reasons that are substantive (i.e. it can facilitate more socially robust decision making), normative (i.e. it is the right thing to do for reasons of democracy, equality and justice), or instrumental (i.e. it provides social intelligence to realise pre-committed objectives and avoid adverse public reactions) (Stirling, 2008; Sykes and Macnaghten, 2013: 95). Many of our participants heuristically understood co-development as being helpful to support gene drive technological development that is efficacious and just, for substantive and normative reasons. However, in practice, our data suggests that many participants slipped into more reductive and instrumental framings of co-development, in order to enhance acceptance of gene drive solutions in Mali and prepare the ground for field trials of a technology that is being developed in and funded from the Global North. Co-development can be interpreted in this respect as a tool to enable successful project management, as a site of de-politicisation (of the social and political dimensions of gene drive) and as a means to establish Mali as a laboratory of experimentation for a new technology. We discuss each of these interpretations below.

4.1. Co-development as a project management tool

The key goals of Target Malaria are to develop and test gene drive mosquitoes – this is what the research consortium has been set up to achieve. Given this starting point, it is perhaps not surprising that the dominant framing of co-development that emerges from the data is of co-development as a *project management tool*. A key element of this approach is conducting adequate risk assessment and obtaining the necessary regulatory approval, which in turn require securing community participation and consent (Delborne et al., 2020). The trials take place in villages where researchers need access to people's houses to collect mosquitoes for post-release monitoring, which necessitates community support and the building of trust between researchers and the local population (Barry et al., 2020). Literacy and education levels in Mali are low, particularly in rural villages, and many people do not know what causes malaria (Marshall et al., 2010). Outreach and education are therefore viewed as essential to establish the necessary capacities and conditions within communities for them to provide informed consent. This relationship-building requires education programmes about the research and about malaria more broadly, particularly about how it is transmitted.

The co-development of institutions (e.g. regulatory approval processes) and building scientific capacity are important elements of co-development as project management. The opportunity to co-develop the science and bring much-needed scientific training and resources is seen as being critical for Malians to develop and assert their own scientific independence and socio-economic transformation. This capacity-building sits comfortably with regional ambitions that gene drive technology become one of Africa's three priority technologies (AUDA/NEPAD, 2020). Our findings complement Barry et al.'s (2020) investigation of community motivations for engaging with Target Malaria in Burkina Faso. They found that people in Bana, Burkina Faso, participated in Target Malaria's project because of their desire to eradicate malaria and address their vulnerability to the disease as well as the desire for capacity building and a sense of pride (for their village).

While Malian participants understood co-development to be primarily concerned with securing acceptance and outreach, UK participants were in contrast more concerned with building capacity and sharing knowledge within the team. Despite these differences in the meaning assigned to co-development, both sets of views were largely driven by a similar and shared goal to enable effective management of the project and propel it along a trajectory to develop and test gene drive mosquitoes in Africa, under difficult political circumstances and in a context of fragile, weak or non-existing institutions. In this context, local and African expert knowledge is recognised only insofar as it supports the implementation of the technology that is developed by Target Malaria. Co-development becomes a vector through which to organise and control the experimental conditions, local reception and effective adoption of a largely predefined technological trajectory/project.

4.2. Co-development as depoliticisation

Our data suggests that co-development also functions as a legitimating tool which serves to *depoliticise* gene drive mosquitos, in the sense of limiting the democratic exercise of power by those who are subjected to those technologies (in this case, the inhabitants of the territories in which gene drive mosquitoes are to be released). By emphasising a rhetoric of dialogue and co-production, the concept of co-development lends legitimacy to Target Malaria's goals. At the same time, it renders invisible the political dimensions of gene drive development and deployment in a context that is socially and politically complex and fragile, and in which there is actually little opportunity to reject or critique the technology being proposed and its implementation. Co-development is explicitly positioned as an enabler of democratic decision-making by establishing new institutions and practices to open up the technology to a more diverse set of actors. But, paradoxically, it does so by simultaneously depoliticising gene drive as a technology and a socio-environmental intervention, whose deployment requires adhering to particular logics, ideologies, interests and power relations. In doing so, this framing of co-development appears to allow for little agency or the sharing of power in shaping gene drive research or its outcomes beyond a pre-determined trajectory, one defined by researchers and funders largely based outside of Mali.

Of these, one of most influential actors in Global health and the main funder of Target Malaria is the BMGF. It retains a significant influence on how co-development is framed, shaping project design, goals, management and communications. As pointed out by Schurman (2018: 190), in the BMGF "plans and ideas flow in a downward direction far more readily than they flow upward. As a result, the voices and perspectives of the foundation's intended beneficiaries quickly disappear from the picture". Co-development, as described by many of our participants, outwardly aspires to stand in contrast to this 'neo-colonial' approach to Global health. However, our findings suggest in practice a strategic approach to co-development exists that is employed largely to persuade Malians and facilitate the downward flow of ideas and technology, aligning with the world view and top-down approach of the BMGF (Fejerskov, 2017). Further, the BMGF shapes co-development through its influence on how gene drive mosquitos are planned to be regulated and communicated to African publics, often achieved through large injections of cash to public relations firms and development agencies

(Cohen, 2017) to 'increase awareness and understanding of possible gene drive applications for public good purposes within international policy forums' and 'to enhance awareness, strengthen regulatory bodies and build regulatory research capacity relating to genetically based vector control technologies to ensure adequate capabilities to manage their deployment across the African Union' (BMGF, 2020). These particular logics, ontologies, interests and power relations are masked behind the buzzword of co-development and its heuristic, normative appeal.

At the same time, co-development reflects in part a genuine ambition by the gene drive community to consider the broader societal implications of their projects, open up research decisions through collaborations and take responsibility for the longer-term effects of their work (Douglas, 2003; Stilgoe et al., 2013). This has led to the opening up of previously expert-dominated spaces in Mali, such as the insectary, and propelled community education about malaria. By taking on these social responsibilities (Douglas, 2003), Target Malaria and the BMGF have however taken over remits that are traditionally a state responsibility and which may in turn create conflicts of interest. Many of our participants recognised that Malians will need to decide themselves whether or not to deploy gene drive mosquitoes. However, in the absence of strong democratic institutions and resources for independent and impartial education and regulatory development, the gene drive community feels a responsibility to help foster education and develop the regulations needed to assess an application to release gene drive mosquitoes in Mali. This aligns with BMGF's explicit aim to shape regulatory frameworks in Africa in ways that support the development and testing of gene drive mosquitoes. In this space, Target Malaria is an influential and well-resourced actor. There is little social science or humanities capacity and few activist movements in Mali which might serve as a critical counterbalance, and no social science research is funded through the BMGF in relation to the local effects of gene drive mosquito research. This reflects a situation in Africa more generally whereby there is little interrogation of gene drive or its governance.

4.3. *Mali as a laboratory for technological experimentation*

Our data suggest that the co-development narrative may be facilitating the treatment of Mali, a country characterised by extreme poverty, conflict and weak institutions, as a *laboratory for technological experimentation* in global health. There is little doubt that malaria eradication is a crisis that has significant economic costs and is both a cause and consequence of poverty (AUDA/NEPAD, 2020). Encouraged by extensive BMGF funding, the African Union's High-Level Panel on Emerging Technologies has singled out gene drive mosquitoes as one of three priority technologies to contribute to solving the malaria problem (AUDA/NEPAD, 2020). When combined with the Malian desire for self-sufficiency and scientific independence, these are favourable political conditions for using countries like Mali as laboratories of gene drive development. The Malian desire for self-sufficiency and independence aligns with the adoption of the technology, as exemplified by the arguments of some of our interviewees that gene drive is an opportunity to break established neo-colonialism power imbalances where science and technologies are developed in high-income countries and imported into Africa. Co-development in this respect leverages a narrative of African independence and suggests that Africans can control the technology and eventually own it in order to develop independently from the Global North. This narrative is not accompanied, however, by a systematic debate on what controlling this technology may involve in practice, especially given the highly invasive and unpredictable effects of releasing gene drive insects into the wild. The narrative of co-development as a tool to support African technological ambitions is also undermined by the absence of agreements (or even discussion) on whether and how the technology will be owned in Africa or Mali, with the African Union Development Agency stating that ownership of intellectual property for gene drive is an 'issue of concern that needs to be addressed' (AU and NEPAD, 2018: 30).

5. Conclusions

Often presented as an opportunity for inclusive, culturally-sensitive and responsible innovation, the umbrella term of co-development is linked to the rise in popularity of participatory approaches to science, technology and innovation (Nature editorial, 2018; Pansera and Owen, 2018). This paper contributes to this growing literature on these approaches in research that crosses the Global South/North. We have highlighted how co-development is being employed to foster new and more inclusive, situated engagement practices for gene drive through its role as a project management tool. In this role, it strategically enables product development and prepares for deployment of a particular type of response to malaria, one that is concerned with universal, advanced technology and engineering solutions (Leach and Scoones, 2006) as techno-fixes for societal challenges (Sarewitz and Nelson, 2008). Considerable funding is being pumped into Africa to ensure that institutions and local communities are prepared to accept and deploy gene drive mosquitoes – building on a broader political context where science and technology are viewed as the cornerstone of Africa's socio-economic transformation (AUDA/NEPAD, 2020).

Our study reveals the way in which Mali's political and economic context enables co-development to extend the influence and interests of actors from the Global North into areas of state responsibility such as regulatory development, whilst depoliticising the technology, masking power relations and closing down opportunities for substantive debate and democratic agency. The possible deployment of gene drive is seen simply as a stage in a pre-defined technological trajectory, one set by those with limited democratic accountability. There is a risk that co-development principally serves to 'prepare the ground' in countries such as Mali, establishing these as laboratories of experimentation with technology-friendly regulatory regimes (Petryna, 2009; Sunder Rajan, 2016; Tilley 2011). In this way, co-development inherits criticisms of the "international development" paradigm guiding many philanthropic initiatives bridging the Global South/North by positioning gene drive as a universal fix which assumes malaria (and poverty) is an engineering problem which can be solved by a single science and technology solution applied across Africa, regardless of cultural, political and historical context (Fejerskov, 2017; Leach and Scoones, 2006; Schurman, 2018; Cousins et al., 2021).

To avoid this, we suggest those funding gene drive projects for global health reconfigure and reframe their programmes to make space for meaningful, substantive deliberation and independent questioning of their very purpose, practices and envisioned outcomes. We suggest this be used to support debate and foster democratic agency and decision-making processes. This, however, pre-supposes the existence of democratic institutions which cannot be taken for granted. Our study raises questions around the conditions - and locations - under which innovative technologies for global health such as gene drives should be trialled and introduced.: While the selection of Mali was presented as based largely on scientific criteria (Mali is home to world-class entomologists and the Malaria Research and Training Center), the enormous political and social challenges facing the country make it simultaneously both deserving of urgent help and vulnerable to technocentric solutions driven by influential, rich investors.

The terms, objectives and practice of co-development are being determined by those with power, resources and little democratic accountability. However, it is not simply a case of UK partners fostering though coercive means a new technology on Malians, it is something that at least those Malians in the research consortium and in policy also welcome. Co-development may be a useful means to engage Malian communities in order to gain consent for field trials, but, in its current configuration, it is not suited to developing socially robust, democratic decision-making frameworks for the governance of gene drive.

CRediT author statement

Sarah Hartley: Conceptualization, Methodology, Formal analysis, Writing – original draft, Katie Ledingham Data collection, Formal analysis, Writing – review & editing, Richard Owen: Writing – review & editing, Sabina Leonelli: Writing – review & editing, Samba Diarra: Data collection, Reviewing, Samba Diop: Reviewing.

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