Youth perspectives on gene drive technologies for malaria control in Tanzania

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Abstract

Background

Gene drive-modified mosquitoes (GDMMs) present a promising innovation for malaria control in sub-Saharan Africa. However, their success depends on public understanding and acceptance, particularly among the youth, who represent a significant share of the population. This study investigated perceptions of young people (age: 15–35) in Tanzania regarding malaria, the potential of GDMMs in accelerating control efforts, and the role of youth in supporting the success of such novel technologies.

Methods

This explorative qualitative study involved nine focus group discussions with six youth groups, including motorcycle taxi riders, soccer teams, arts and crafts groups, sports coaches, and medical students. Participants were introduced to GDMMs through brief presentations, followed by guided discussions. Transcripts were analyzed using NVivo 12 Plus, applying both inductive and deductive thematic analysis.

Results

Participants expressed strong interest in contributing to malaria control, and showed enthusiasm for new technologies like GDMMs. However, they demonstrated limited understanding of malaria transmission, particularly the role of mosquitoes. Malaria was perceived as a routine, manageable illness, contributing to low perception of its risk. Participants expressed surprise over the malaria statistics and challenges in the country, and voiced frustration over being uninformed and excluded from national strategies. Despite initial skepticism toward GDMMs, youth expressed willingness to support malaria control efforts if engaged early through trusted messengers, creative outreach, peer education, and sustained, inclusive involvement. This included willingness to inform and educate communities about GDMMs.

Conclusion

This study highlights both the potential and the unmet needs of youth in malaria-endemic settings regarding their role in malaria control and the introduction of GDMMs. While youth are enthusiastic about innovation and eager to contribute, their limited understanding of malaria transmission and feelings of exclusion from existing efforts present barriers to engagement. Meaningful, early, inclusive, and sustained involvement is essential to ensure informed youth participation and build public support for emerging interventions like GDMMs.

Introduction

Gene drive-modified mosquitoes (GDMMs) have emerged as a promising innovative technology aimed at either suppressing mosquito populations or rendering them incapable of transmitting malaria parasites [1–3]. Although the scientific promise of GDMMs is substantial, their real-world success is heavily contingent on a

combination technical efficacy, community understanding and acceptance, responsive governance, and the development of context-specific regulatory and technical capacities [4, 5]. Community understanding and acceptance is perhaps the most pivotal, as with any public health intervention that directly interacts with communities, gaining broad and informed support is essential for successful implementation [6, 7].

To assess the level of acceptance, however, communities must not be treated as monolithic entities. A key step drawn from the principles of social marketing is the segmentation of communities into distinct subgroups based on characteristics such as age, gender, social roles, or vulnerability to malaria [8, 9]. This segmentation enables tailored engagement strategies that address the unique concerns, values, and motivations of different groups, thereby improving communication effectiveness, trust, and eventual uptake [8]. This is especially crucial in the case of GDMMs, which are both novel and complex, and carry perceived risks that may be differently interpreted by various community segments [10–14]. Engaging with these nuances from the outset helps avoid blanket messaging that risks alienating or misunderstanding key groups [15].

One particularly influential segment that warrants targeted attention is the youth demographic. In the context of this study, we considered Afrucan Union's definition of youth as individuals aged 15 to 35 years [16]. Youth make up over one-third of Africa's population [16], and in many malaria-endemic settings, they are not only the most mobile and connected group but also key agents of social change. Engaging youth meaningfully in discussions around GDMMs is both strategic and imperative, as their participation can help bridge generational divides in understanding, enhance technology literacy in communities, and foster early buy-in for interventions that may only show their full impact years down the line. However, despite their demographic and societal importance, insights, concerns and recommendations of youth have often been overlooked in policy and research on malaria control. This oversight represents a missed opportunity, one that this study is attempting to address.

This study therefore aimed to assess the perceptions, informational needs, and key recommendations of Tanzanian youth on malaria, current control measures, and potential use of gene drives as a new intervention for malaria control and elimination.

Methods

Study site and participants

This study was conducted in Ifakara Town Council, in the Kilombero Valley of southern Tanzania. The council has a dynamic mix of rural and peri-urban settings and has an estimated population of approximately 290,000 people, across 19 administrative wards [17]. A significant proportion of the residents are engaged in rice farming, which is the dominant economic activity in the region, often supplemented by small-scale businesses, fishing along the Kilombero River, and other forms of small-scale irrigation-supported agriculture. Malaria transmission in the town center is relatively low [18], but Ifakara is surrounded by high-transmission areas, placing it at continued risk of malaria resurgence and outbreaks [19].

The study sample comprised youth from multiple wards in the administrative council. A combination of convenience and snowball sampling was used to recruit participants. Initial contacts were made through

consultations with community leaders, who helped identify known youth groups. These groups were then approached and asked to participate in the discussions. Groups that consented to participate were also asked to recommend other groups for inclusion. Ultimately, six distinct youth groups were engaged: motorcycle taxi (*boda-boda*) riders, arts and crafts groups, men's soccer teams, women's soccer teams, soccer coaches, and college students from a local medical school (St. Francis University College of Health and Allied Sciences). The student group consisted exclusively of individuals enrolled at a local medical college.

Study procedure

Exploratory qualitative approach was used to investigate perspectives of the youth on the need for and potential of GDMMs for malaria control and elimination. A total of nine focus group discussions (FGDs) were conducted: two each with the boda-boda riders, male soccer teams, and female soccer teams, and one each with an arts-and-crafts group, soccer coaches, and college students. Each FGD comprised 6–10 participants, using a semi-structured guide covering four broad thematic areas: i) perspectives and lived experiences with malaria; ii) perceptions and experiences with technology in general; iii) perceptions and concerns about GDMMs; iv) interest in being involved in GDMM-related research and implementation efforts, and v) insights on meaningful and appropriate strategies for engaging the youth in GDMMs initiatives.

To ensure informed and meaningful contributions during discussions on GDMMs, participants were first given a brief presentation outlining the current state of malaria burden and control, the concept of gene drive technologies, how GDMMs work, and their intended role in malaria control. This was followed by an open question-and-answer session in which youth were encouraged to raise any concerns or seek clarification. Only after all questions had been addressed did the moderated discussions on GDMMs begin. Each FGD session lasted between one and two hours, depending on the group dynamics and level of engagement. The study was conducted from September to November 2024.

Data processing and analysis

All FGD audio recordings were transcribed and translated into English, with accompanying field notes integrated into the final transcripts. Transcription and translation were conducted by GM and MF. The final verbatim transcripts were imported into NVivo 12 Plus software to facilitate systematic coding and thematic analysis [20]. A combination of deductive and inductive coding approaches was applied. The FGD guide informed the creation of deductive codes based on predefined broad themes, and inductive codes were added through careful reading and interpretation of participant responses. Recurrent themes were identified, and direct quotations were used to support the views of the participants. Nine major themes that emerged from the analysis included: i) understanding of malaria transmission, ii) perceptions of malaria, iii) general views on technology, iv) perceptions of GDMMs, v) youth involvement in GDMMs, vi) youth engagement strategies, vii) building youth credibility, viii) leveraging entertainment for engagement, and ix) gender dynamics in youth participation.

Results

Characteristics of study participants

A total of 75 youth representatives participated in this study. Of these, 51 were male, and 24 were female. A notable distinction emerged within the women's soccer teams, where all participants were between 12 and 17 years old, and concurrently enrolled as students in various secondary schools within the study area. In this case their assent was obtained, as well as consent obtained from their coaches, who were also teachers in their respective schools, and assents were obtained from the participants. This contrasts with the other groups, where participants ranged in age from 18 to 45 years. A detailed breakdown of participant demographics by group is provided in Table 1.

Table 1
Composition and demographic profiles of youth groups participating in the study

Group	Age range	Males	Females	Total
Soccer team – Men	15–35	18	0	18
Soccer teams – Women	12–17	0	18	18
Soccer coaches	30–45	5	1	6
University students	20–30	6	2	8
Boda-boda riders	18–37	16	0	16
Arts & crafts club members	25–40	6	3	9
Total	12–45	51	24	75

Understanding of malaria transmission

While a majority of the participants demonstrated a good understanding of malaria symptoms and its general causes, there were notable gaps in their comprehension of how malaria is transmitted, particularly the role of mosquitoes. Although most knew that the female *Anopheles* mosquito is responsible for spreading the disease, only a few, even among medical students, could accurately explain the transmission processes. The concept of mosquito species was poorly understood; mosquitoes were often seen as a single, undifferentiated group. When attempting to differentiate them, participants commonly referred to categories such as 'male and female mosquitoes', 'malaria-transmitting and non-malaria mosquitoes', or 'black and grey mosquitoes. Many believed that both male and female mosquitoes bite humans, though only females transmit malaria. Some of the participants also believed that female mosquitoes are born with malaria parasites and pass them on through biting.

When presented with national malaria statistics and Tanzania's malaria strategic plans, many participants expressed surprise, frustration and disbelief, stating that it was the first time they were hearing about the numbers, challenges and initiatives. They questioned whether the strategies for malaria control were intended only for government and researchers to implement, or whether communities were expected to play a role as well. If the latter were true, they wondered why such information had not been shared more widely. Participants were also surprised to learn about emerging challenges in malaria control, such as insecticide

resistance and changes in mosquito behavior, and asked why these issues had not been communicated to the general public. This lack of information led to a strong sense of exclusion and neglect, particularly among those who felt they were in a position to influence others, but had been left uninformed. One participant, a local soccer coach, voiced his frustration:

“I teach in this neighborhood where you are based, but why am I hearing about this for the first time? Are these strategies just for you and the government to work on, or is there a part for us to play? Why are you leaving us out? If malaria is still as serious as you say, why don’t we ever hear about it? There used to be campaigns on radio and TVs, but these days they are no longer, and you see, because of that we even forget that this disease is even a problem.” (Male coach)

Perceptions of malaria

The participants commonly referred to malaria using phrases like ‘a normal thing’, ‘everyday illness’, ‘fever’, ‘a routine disease’. When asked whether they had personally experienced malaria, a majority of the participants reported that they had never had it, while others struggled to recall the last time they were infected. Only five participants across all groups reported having had malaria recently, and one individual mentioned hospitalization due to the illness. All in all, malaria was perceived as a familiar but manageable disease as this boda-boda rider elaborated:

"Malaria is not a big issue these days. We know it is there, and we know we could get it, but that is not worrying. I can get tested anywhere, and treatment is easily available. It does not kill, and it does not make you too sick, you rarely hear someone die of malaria these days." (Boda-boda rider)

Participants emphasized that this shift was credited to significant improvements in malaria prevention, diagnosis, and treatment. They credited increased access to insecticide-treated nets, rapid diagnostic tests, and more tolerable medication options had reduced both fear and perceived urgency around the disease. In semi-urban areas, many youths felt that malaria was declining and no longer serious, with some even expressing optimism that it could be eliminated in their lifetime.

Several participants, particularly students, stressed that malaria was not considered as concerning as other health issues. They contrasted malaria with HIV/AIDS and other sexually transmitted infections (STIs), which they described as carrying greater stigma, longer-term consequences, and more disruptive effects on young people’s lives. By comparison, malaria was viewed as more treatable and less socially threatening, as one student explained:

“Malaria is not as big a concern for the youth, not like HIV. There are a lot worse diseases one could get, and people know that. People are just not afraid of it. So if you want youth to be interested in malaria, you need to improve their perception of risk first.” (Female Student)

Nevertheless, participants from rural and itinerant populations, especially the boda-boda riders, expressed a different reality. They emphasized that malaria still thrives in poorer areas lacking essential infrastructure and often left behind in elimination efforts. Stagnant water, poor housing, and limited access to health facilities

were described as persistent drivers of transmission. These participants expressed frustration and doubt about whether malaria would ever be eliminated, pointing to the inadequacy of current strategies:

"There are places where people live but even a boda-boda cannot get there, they have not even seen bed nets. How can malaria be eliminated in such areas? So long as mosquitoes are there, malaria will always be there. Our environment will not allow it to disappear." (Boda-boda rider)

Moreover, as the discussions became more in-depth about the disease, concerns about effectiveness of diagnosis and treatment began to arise. Participants described experiences where test results did not match their symptoms, for example testing negative despite having classic malaria symptoms, or testing positive without any symptoms at all, or using drugs, but not recovering. These inconsistencies led to doubts about both the accuracy of diagnostic tests and the effectiveness of available medications, as one participant explained:

"Every time I test for malaria I am always told that I have it. Sometimes I use a full malaria dose but I do not get better. Sometimes I think the tests are not telling the truth, and sometimes I think the drugs are not working. (Boda-boda rider)

General views on technology

Across all groups, youth considered technological advancements to represent development, progress, modernity, transformation, new ways of life, something new, and better ways of doing things. When asked about the technologies they were familiar with, mobile banking, smartphones, electricity, motorcycles, IV drips, and digital apps were all mentioned as things that had transformed their daily routines. For many, the appeal of technology was closely tied to efficiency and access. They described how previously slow or impossible tasks such as sending money, sharing news and information, and getting services could now be done within seconds. Technology was credited with bridging distance, creating income opportunities, and opening up educational and medical access in ways previous generations could only imagine. One participant elaborated:

"In the past, if you needed medical help, you just knew you would have to spend the whole day in the hospital. These days you do not even need to go to the hospital. Same with bank services, you never see long lines in the banks like in the past." (Male soccer player).

This admiration was reported to coexist with skepticism, especially during the early days of any new innovation. The youth shared numerous personal and community stories of how technologies that are now fully accepted were at first met with fear, mistrust, or superstition. Some described people believing mobile phones could drain their blood, the fast loans were satanic, or IV fluids were designed to kill. Others admitted they personally rejected the use of sim banking (mobile phone banking) and accelerated credit facilities commonly offered by local microfinance banks, suspecting the service provides as being members of exploitative secret societies, loosely framed as "freemasonry". One participant explained their experience with mobile phone banking:

*"I used to keep my money at home or carry it with me. I knew it was not safe, but that was the safest I had at the time. When sim banking (i.*e. Mobile phone banking*) came, I did not believe it at all, I thought those people*

were thieves and wanted to take my money. I did not trust them at all. I still do not trust them, because, how can money be so available like that? But I see a lot of my friends are using it, so I am easing my worries, but it takes time." (Boda-boda rider)

Other participants expressed concerns about ethics, privacy, and unintended consequences. Technologies like artificial intelligence were seen as helpful but potentially risky if not well regulated. These youth feared not the tool, but its potential misuse, especially in systems where laws may be weak and oversight inconsistent. One student said:

"Medicine is grounded in ethics and privacy, so we are constrained by that. As a doctor I do worry that the AI may not know those values, so for me, the fear of being replaced is not as big as the fear of losing those values." (Male student)

The process of gradual acceptance through exposure and reassurance was emphasized in every group. What ultimately changed people's minds was not just information, but seeing others being safe and benefit, particularly friends, siblings, or neighbors. Youth repeatedly noted that community proof was a better determinant of technology acceptance than the official instructions. In this regard, they emphasized that visual demonstrations, relatable examples, and community conversations, led by people they know and trust, are necessary to move from suspicion to support, as elaborated by this participant:

"If someone like me uses it and is okay, then people will believe. If I tell my friends that something is safe because I have experienced it, they will trust my experience more than they will trust your knowledge. That is just the way it is with it is with people." (Male soccer player)

Perceptions of GDMMs

The introduction to the technology of GDMMs evoked reactions of fascination, disbelief and skepticism. For most participants, the very idea that scientists could genetically modify mosquitoes to prevent them from spreading malaria sounded more like science fiction than fact. Their first responses, captured across multiple groups, included fascination, laughter, disbelief, discomfort and fear. They asked questions about what the GDMMs looked like, how they would be released, whether they behaved like the normal mosquitoes, and how people would know if they have seen one. When teased about what they would do if these modified mosquitoes were actually released into the environment, a majority of the participants gave the same reaction of fear and concerns as this:

"If you release today? I will run away, I will hide, or I will kill them, I will be too afraid." (Male soccer player)

Several participants tried to make sense of GDMMs by drawing analogies with familiar concepts from their everyday lives, such as sports and farming. Some compared it to planting "high-performing" seeds in agriculture, particularly hybrid crops that are designed to spread or survive better, while others likened the mosquito mating process to soccer passing strategies, where each mosquito passes the gene forward, increasing its spread through the population. One soccer player said:

"These mosquitoes are like soccer players; they can pass on the gene to one another until they get to where you want them to." (Male soccer player)

Participants explained that it would not be enough for them to just be informed that these mosquitoes are safe, it was especially not enough for them to be told this by people they were unfamiliar with, even if they are Tanzanian researchers. They re-emphasized the importance of getting information about new technologies like this from people they were familiar with and trusted, as this participant said:

"No, we would not believe you, we do not know you well enough, so we do not know if you are truthful. It has to be backed up and endorsed by the government, and our people that we trust must also support it. (Male soccer player)

The more educated participants, particularly medical students, raised more technical concerns such as long-term monitoring, regulatory oversight, and the reversibility of gene drive interventions if unintended consequences emerged. They raised concerns on whether modified mosquitoes could potentially carry or amplify other pathogens, and how their release might affect broader ecological systems. One participant articulated this concern as follows:

"What if the modified mosquitoes mutate or interact badly with something else in the environment? What if they behave differently than expected and cause more harm than good? What systems are in place to detect that early, and correct?" (Female student).

Participants also raised concern that decisions about whether, when, and where to release GDMMs might be made without the consultation, understanding, or consent of the locals. They questioned who holds the authority to approve such interventions, and whether their own communities would have any meaningful role in that process. This unease was shaped by the lived experiences of the participants with previous health interventions, such as mass drug administration for lymphatic filariasis (ivermectin), school-based deworming campaigns, and vaccination programs. Participants described these earlier initiatives as often top-down and coercive, with limited explanation, dialogue, or room for refusal. Many felt they had little to no decision-making power, even when interventions were targeting their own bodies, their children and their communities. One participant shared a personal experience from the COVID-19 vaccine rollout:

"With COVID vaccine, they came to my house and said I needed to be vaccinated. I asked a lot of questions, but they could not answer in a way that satisfied me, so I just lied to them and said that I had already been vaccinated. What if this is the same? (Female artist).

Despite the concerns, a majority of the participants said they were willing to learn more, and possibly even support the technology, but only after clear, consistent, and repeated education. They asked for visual demonstrations, real-world examples from other countries, and most importantly, the time and space to reflect and ask questions before being expected to advocate for the technology themselves.

"Teach us how it works, teach us well. If we can explain it clearly to our people, we can even support it." (Male artist).

Youth involvement in GDMMs-related efforts

Across all focus groups, youth expressed a strong desire to be actively involved in malaria control efforts, including the introduction of novel tools like GDMMs. They described their potential contributions in three main ways. Firstly, they emphasized their demographic strength, noting that as the largest segment of the

population, their collective choices and behaviors have significant influence. Secondly, they saw themselves as cultural and technological translators, capable of making scientific concepts more relatable within their communities. Thirdly, they highlighted that their comfort with innovation, fluency in digital tools, and contemporary communication often make them the go-to resource for others seeking to understand and adopt new technologies. One participant elaborated saying:

"We can teach our parents, they will listen to us on this. They already come to us for knowledge and advice regarding technologies; we can use that as an opportunity." (Male soccer player)

The participants emphasized their unique position in their communities, noting that their mobility, accessibility, and adaptability make them powerful agents for reaching diverse audiences, especially in remote or underserved areas where other groups may struggle to gain access. Whether as boda-boda riders moving across villages daily, soccer players drawing large crowds to matches, or students embedded in peer networks and clubs across the country. One participant said:

"We are with people more than you. We are always in the community, so they know us, and when it comes to trust, they will trust us more because they know us. So we can prepare them, so that when you go to them, they have already heard about this." (Boda-boda rider)

Participants also spoke about the feasibility and practicality of involving youth. They noted that youth groups are among the most organized and accessible segments of the community. They explained that most youth already belong to networks or groups that meet regularly, such as schools, colleges, soccer teams, vocational training centers, or boda-boda groups. This makes them easy to reach, and often much more affordable to engage than older or more dispersed community groups. One participant said:

"Almost all the youth belong to one group or another. You don't have to search for youth, we are already organized. Many people our age either in colleges or secondary schools. Those that have dropped out of school are either boda-boda, or belong to soccer teams in their communities, so you can easily access them. We are the most organized age group, and honestly, the easiest to work with." (Boda-boda rider)

They expressed a strong willingness to contribute even with minimal resources, provided they are supported to carry out their roles effectively and acknowledged for their efforts. Many explained that small gestures of recognition, such as certificates, branded T-shirts, or public acknowledgment, go a long way in validating their contributions and keeping them engaged, as this participant said:

"After we have been educated, on days you need people to advocate, you let us know and we can go to the communities and pass on the knowledge and the information. We can carry flags about the technology, and wear identifying t-shirts so that people can spot us." (Boda-boda rider)

Aside from the capacity, the participants also wanted to be involved because they felt a moral and civic responsibility to shape the health and future of their communities. Several spoke passionately about wanting to be remembered as the generation that finally helped end malaria, and about the pride they would feel contributing to something larger than themselves. One young participant said:

“If malaria ends in our generation, we want to be remembered as part of that. Not just watching from the side.” (Female soccer player)

Youth engagement strategies

Participants across all groups offered thoughtful, creative, and contextual strategies for how they could be engaged in GDMMs advocacy, and how they in turn could reach others. Throughout the discussions, they made it clear that they did not want to be engaged temporarily or symbolically; if GDMMs or any other malaria control strategies are to succeed with youth support, they recommended for sustained and long-term engagement rather than short-term campaigns. They requested to be equipped with both the knowledge, platforms, roles, and recognition that endure beyond a single project cycle. They wanted to be involved as co-creators, mobilizers, and ambassadors, as one participant said:

"Involve us in the planning, training, and delivery. We are not just here to listen. We are here to make it work." (Female soccer player)

Participants advocated for peer-to-peer education, noting that young people are more likely to trust, engage with, and act on messages from fellow youth. This peer learning model was seen as effective as it builds on shared language, experience, and communication styles. However, they emphasized that youth messengers must be well-trained, confident, and credible. One participant said:

"Find youth that are convincing to be role models, and train those. You cannot train everyone, but you can select the convincing ones, and they can pass on the knowledge to others." (Male soccer player)

As for delivery methods, participants preferred engaging, visual, and interactive formats. They advised that education on GDMMs be conducted through short seminars or workshops of between three and five days, to allow time for questions, hands-on demonstrations, and meaningful reflection. This was said to help participants develop accurate understanding and confidence to explain the technology effectively in their communities. One participant said:

*"It should be more than three days. It should be long enough that we are well educated and have all the questions answered, but not too long that we feel bored. Also, make it simple to understand and simple for us to explain later.” (*Male student)

Participants called for ongoing support, refresher trainings, and the formation of youth teams or fellowships that could sustain momentum and remain involved long-term. They emphasized the value of tracking progress, both their own and the community’s. They proposed basic tools for monitoring who has been reached, what questions people ask, and how acceptance evolves over time. They also proposed formation of structured youth groups or fellowships focused on malaria elimination and gene drive education. These could be modeled on school health clubs, but adapted for both in-school and out-of-school youth.

They recommended branding these groups with names like “malaria ambassadors” or “youth champions for innovation,” with clear expectations, visibility in their communities, and regular training refreshers. They noted that in-school youth will graduate, and community dynamics shift. Any long-term strategy must include ways to renew and refresh the youth cohort, such as annual fellowships, mentorship chains, or incentives for peer recruitment. One student said:

"Create a group of malaria ambassadors or malaria champions or malaria team, with all the characteristics you need. You can engage with them regularly, and task them with reaching the communities in ways that you cannot. The group can expand and pass on the knowledge and responsibilities, and make this work very easy for you." (Female Student)

Building the credibility of the youth and creating partnerships with other groups

Across all groups, participants emphasized that their voices alone would not be enough to build community-wide trust in unfamiliar technologies such as GDMMs. While they recognized their own capacity to reach peers and younger community members, they also acknowledged the need for partnering with trusted local influencers such as elders, religious leaders and community leaders, in shaping perceptions and legitimizing messages. They recommended a partnership model in which youth are not only trained and equipped as ambassadors, but also publicly endorsed by trusted community leaders. For instance, when youth ambassadors are introduced at educational sessions within the communities, those introductions should come from leaders known and trusted by the audience. At the same time, youth cautioned that the elders themselves must be well informed to maintain their credibility. One participant explained:

"We youth are the most connected, but we are not always respected. People will listen more if our village or religious leaders come with us, and speak too." (Boda-boda rider)

Others emphasized that for messages delivered by youth to be taken seriously, they would need to be accompanied and supported by trusted professionals. They explained that the presence of experts could not only help address technical questions about the technology, but also lend credibility to the youth, reinforcing their role as legitimate messengers within the community. This professional backing, they noted, would strengthen community confidence in both the message and the messenger. As one participant put it:

"We cannot go alone, they will not believe us, they will say 'don't we know you? You have not gone to school, so how come you are talking like a scientist?' *But if you come with us and you talk to them, they will believe you. And if they see us with you a lot, they will learn to believe us too."* (Female soccer player)

Leveraging entertainment for engagement

Across all groups, participants emphasized that effective engagement must go beyond serious messaging, to be enjoyable, visible, and emotionally engaging. They highlighted the importance of using local language, tone, and dialect to ensure messages are relatable. They consistently pointed to cultural and recreational platforms such as sports bonanzas, music competitions, dance, drama, street art, and illustrated books, as trusted and memorable ways to connect with the broader community, enhance understanding, and facilitating dialogue.

"Even when the topic is serious, if the atmosphere is good, people will take it in." (Female soccer player)

Soccer bonanzas were the most frequently mentioned platform by all the participants. Participants shared examples of past health and political campaigns and business promotions that successfully used soccer bonanzas to capture attention and deliver messages. Based on these experiences, participants proposed a similar approach: integrating GDMM-related education directly into the event through branded team kits, halftime messages, educational booths, or interactive Q&A sessions led by emcees. They emphasized that the

informal, festive nature of such events provides a non-threatening and highly engaging environment in which people are more open to listening, asking questions, and learning. One participant elaborated this saying:

"You can organize "bonanzas", you decide how many teams you want to participate. You can give small prizes to the winners, even just balls or T-shirts. Make sure to brand them with your logos or messages you want exposed. People will talk about it long after the game ends." (Female soccer player)

Female participants, particularly those from women's soccer teams, highlighted the unique opportunity presented by female-led sports events as platforms for community engagement. They noted that such events often attract larger and more diverse audiences, not only for the sport itself but also because of the novelty and cultural significance of seeing women actively participate in spaces traditionally dominated by men. This visibility, they explained, could create a powerful opening for delivering public health messages, especially when those messages are delivered by the players themselves, as this participant elaborated:

"People prefer female competitions to males, as it is still new and exciting for communities to see women compete in sports that are otherwise considered men's. They will come just to see what we do, and they will listen if we give a message there." (Female soccer player)

Beyond sports, participants emphasized the power of arts-based platforms, such as drama, poetry, music, and painting, as culturally resonant tools for explaining complex scientific ideas like GDMMs. The arts group proposed writing and performing educational songs or plays in public spaces such as markets, bus stands, or school assemblies. They also suggested visual strategies, including street murals and community art competitions as impactful ways to engage audiences with low literacy or limited formal education.

"We can write a play, like the ones we used to watch for HIV campaigns. But this time, it will be about mosquitoes and this new thing." (Female artist)

Gender dynamics in youth engagement

A key observation during this study was that a majority of the youth groups outside of school settings were male-dominated. This was especially evident in boda-boda groups, where all participants were men, and soccer teams, a majority of which were men's teams. Arts and crafts groups had a mix of men and women, but were still majority male. According to participants, this skew was due to societal expectations that women, especially once they reach adulthood, are not expected to gather in mixed or public groups unless these are explicitly women-only, as this participant explained:

"Even if she wanted to join the group, people will talk. They will say, 'Why are you hanging out with boys? What are you looking for?'" (Female artist)

Female-only youth groups were rare, and most existing women groups in the area were composed of older women engaged in savings and income-generating activities. The notable exception in this study was the two female soccer teams in the entire council, in contrast to every community having at least one male soccer team. Even here, gendered patterns emerged: the female teams were significantly younger, with most players between 12 and 17 years old, while male teams ranged from 15 to mid-30s. When asked why older girls did not remain active in soccer or other public youth spaces, participants pointed to social pressure, domestic expectations, and stigma. Once girls completed school, they were expected to focus on home responsibilities,

relationships, or income-generating activities. In contrast, boys and men were given social permission, even encouraged to continue participating in recreational or community groups for much longer.

"Once you finish school and you are a girl, people start watching you... They say, 'you are now a woman, stop playing, start preparing for life.' " (Female soccer player)

In mixed-gender focus group discussions, female participants were often noticeably quiet, contributing only when directly invited to speak. This was visibly different from the female-only groups, which were among the most vibrant and engaging discussions in the study. Despite these barriers, young women demonstrated strong leadership potential and interest in participating in education and advocacy.

Discussion

This study provides timely insights into how youth in malaria-endemic communities perceive the disease, technological interventions, and their own role in health-related innovation, particularly the introduction of GDMMs for malaria control. The findings demonstrate that youth are not only open to innovation but are also uniquely positioned as culturally fluent intermediaries between innovation and communities. However, their meaningful inclusion requires approaches that are responsive to their lived realities, cultural constraints, and aspirations for recognition and leadership. A summary of their recommendations on effective engagement strategies is provided on Table 2.

Table 2
Summary of youth recommendations on effective youth engagement

1. Reframe malaria as a personal and urgent issue for the youth; not just children under five and pregnant women
2. Involve locally trusted leaders to introduce and endorse youth-led GDMMs efforts
3. Engage youth as co-creators in planning, training, and outreach for GDMMs
4. Establish diverse peer groups with clear roles and continuous training
5. Use brief, interactive workshops with relatable and accessible content
6. Integrate messages into platforms like sports, music, and art
7. Provide ongoing support, recognition, and refresher trainings
8. Ensure inclusive spaces and leadership roles for young women
9. Monitor engagement using simple tools and regular check-ins
10. Sustain youth involvement through fellowships, mentorship, and recruitment

While some efforts to increase youth involvement in the fight against malaria have been undertaken [21], our study revealed many more opportunities. Participants demonstrated limited understanding of how malaria is transmitted, especially the role of mosquito species and the biological mechanisms of transmission. While they knew that female mosquitoes transmit malaria, few could explain how this occurs, and many held misconceptions, such as believing mosquitoes are born with the parasite. These findings reflect other studies from similar communities, where the actual role of mosquitoes in disease transmission was unclear [22–24].

This limited understanding may have played a part in influencing how youth perceived malaria. Many described it as a familiar and manageable illness, no longer feared or seen as life-threatening. When presented with national and global statistics on malaria cases and deaths, they expressed surprise and disbelief, noting that these figures did not reflect their everyday experiences. This diminished risk perception echoes findings from other studies, where a declining malaria burden has led to complacency, particularly among younger populations [25–28].

Participants reported that public messages about malaria have declined in recent years, which they interpreted as a sign that the threat is lower than before. Evidence from African settings aligns with this perception: nationally representative surveys in Uganda found that only about half of adults reported exposure to malaria messages in the previous months [29], while school-based surveillance in Tanzania reported that just 49% of pupils had been exposed to malaria prevention messages [30], a nearly 50% decline over the past decade [30–33]. Some of the reasons for such decline include fragmented or resource-constrained malaria communication efforts and COVID-19–related disruptions that reduced community outreach and social and behavioral change (SBC) activities across Africa [34–36]. When introduced to more complex challenges like insecticide resistance and changing mosquito behavior, and ongoing efforts and challenges to deal with these, participants expressed frustration at the perceived exclusion from malaria control efforts. This reaction suggests that community members are not indifferent; rather, they wish to play a more active and empowered role in prevention strategies. This aligns with observations from other African contexts, where malaria control and elimination programs increasingly recognize that active community engagement is vital for success [37].

Additionally, a majority of participants could not recall when they last had malaria. At first glance, this might suggest encouraging progress in malaria control, and in some cases it does. For example, a study in 2015 indicated a dramatic decrease in malaria transmission in Ifakara town in nearly decades [38], which is significant enough for people to feel the change. However, such responses should be interpreted with caution in endemic settings, as research shows that in areas with stable malaria transmission, prevalence tends to be higher among older children, adolescents, and adults compared to children under five, particularly due to the accumulation of partial immunity over time [19, 39–42]. These age groups often carry the parasite asymptomatically, acting as silent reservoir that sustain transmission within communities [40–44]. This poses a serious challenge, as individuals who feel healthy may unknowingly contribute to ongoing malaria transmission, particularly to vulnerable populations such as young children and pregnant women [40–43]. As conversation continued, even participants who initially questioned the importance of malaria expressed uncertainty about the hidden risk, noting that diagnosis and treatment did not always reflect their experience, for instance, when tests gave results inconsistent with symptoms, or when treatment failed to bring recovery. Such experiences may reinforce the perception that malaria is both less visible and less urgent, even though transmission persists. This disconnect between the actual and perceived risk highlights a critical need to strengthen community awareness about the persistent but subtle nature of malaria risk, even when symptoms may be absent.

This lowered perception of risk also poses a challenge for mobilizing youth support for novel interventions like GDMMs, which may be seen as disproportionate responses unless the enduring burden of malaria is made visible [44, 45]. To engage youth effectively, the threat of malaria must first be made visible, personal, and relevant once more. This phenomenon is not unique to malaria. In HIV/AIDS campaigns, for example, youth-

focused initiatives succeeded when they used relatable peer narratives to personalize risk and bridge the gap between biomedical urgency and youth perceptions of the disease [46, 47]. Similarly, re-establishing malaria's relevance must be a foundational step in any effort to engage youth around GDMMs. As participants in this study repeatedly emphasized, trust in new interventions is built through emotional connection, contextual clarity, and credible messengers.

Building on their desire for clarity and trustworthy communication, participants expressed strong enthusiasm for technology in general, associating it with modernity, efficiency, and progress. This optimism extended to GDMMs, which was received with a mix of curiosity, hope and concerns, sentiments that have been observed in several studies across Africa [10–14, 48–50]. Participants' caution was shaped in part by past experiences in which health interventions or technologies were introduced without sufficient explanation, community involvement, or visible benefits. These encounters resulted in skepticism and raised questions about the intentions behind engagement efforts. These reflections align with a growing body of evidence emphasizing the need for transparency, local ownership, and meaningful participation to securing public trust and acceptance of novel health technologies [5, 51, 52]. Despite the initial concerns and skepticism, participants demonstrated openness to understanding GDMMs, provided that education is clear, sustained, and youth-driven. They saw themselves as early adopters and technological interpreters within their communities, already supporting others in navigating digital tools. These findings align with broader literature emphasizing the importance of involving youth in public health not merely as recipients of information, but as co-creators and trusted messengers of outreach strategies [53].

Participants emphasized the value of entertainment-based approaches such as sports, music, and visual art as trusted and culturally resonant ways to share, reflect on, and internalize new ideas. These preferences align with broader communication patterns observed in many African settings, where acceptance is often shaped more by peer influence, community dialogue, and tangible demonstrations of benefit than by formal education [54–57]. In the case of GDMMs, where the underlying science is complex and unfamiliar, such creative approaches are especially useful for translating technical concepts into relatable narratives. Participants also stressed the importance of endorsement by trusted figures, such as community and religious leaders, as well as health and technology professionals, to legitimize youth-led messaging. Their support was seen as vital to building broader community trust and acceptance. Together, these insights point to the need for a dual strategy: one that empowers youth as creative communicators while anchoring their efforts within established community structures. Similar multi-level engagement models have proven effective in vaccination campaigns [58–60], and in Burkina Faso, a gene drive research initiative successfully combined youth-driven artistic outreach with public endorsement from local leaders to enhance awareness and acceptance [61].

In this study, gender dynamics emerged as a critical consideration; and that messages targeted to any one youth groups might need to be repackaged differently for other groups. The underrepresentation of young women in public youth groups, coupled with their limited voice in mixed-gender discussions, reflected deep-rooted structural inequalities that must be addressed if engagement efforts are to be truly inclusive. This mirrors findings from studies across sub-Saharan Africa, where adolescent girls' participation in community health forums are constrained by similar factors, limiting their access to information, particularly around sexual and reproductive health, compared to their male peers [62, 63]. These gender dynamics are also observed even among older generation, often necessitating the separation of men and women during focus

group discussions to ensure meaningful female participation [64]. When young women in this study were given space, particularly in female-only settings, they contributed some of the most creative and actionable ideas for community outreach. This underscores the need for gender-sensitive engagement strategies, including the creation of female-only platforms, the integration of gender equity into training programs, and the public affirmation of women leadership roles.

This study had several limitations. First, the youth voices represented here are drawn from a malaria-endemic setting in southern Tanzania. While these insights offer valuable depth, they may not be fully generalizable to youth in other settings in the country or elsewhere in Africa, where social, cultural, and ecological contexts may differ. Second, with the exception of the medical students, the study primarily engaged out-of-school youth and those participating in community groups such as soccer teams, vocational programs, and creative arts groups. As a result, in-school youth primary and secondary schools, who make up a substantial proportion of the youth population, were largely underrepresented unless they were also involved in these community platforms. This limited the diversity of youth perspectives, particularly those of students who may engage with science and health messaging in different ways. In-school youth in primary and secondary schools were not directly included, as the study's initial scope did not target this age group, and their recruitment would have required substantial design changes and additional ethical approvals for working with minors. However, students who were active in community groups, such as soccer teams, were included with their assent and consent from their coaches. Despite these limitations, the study provides rich, in-depth insights into youth perceptions, priorities, and potential roles in advancing community understanding of novel malaria interventions such as GDMMs. These findings can serve as a foundation for future more inclusive studies, and for designing more inclusive and context-responsive youth engagement strategies in future health research and implementation efforts.

Conclusion

This study offers timely insights into how youth in a malaria-endemic settings perceive malaria, emerging technologies like GDMMs, and their potential roles in health innovation. While participants showed strong enthusiasm for technology and a desire to be actively involved, their understanding of malaria transmission was limited, contributing to low-risk perception and skepticism toward novel interventions. Improving baseline knowledge about malaria is therefore critical for enabling informed youth engagement in the development, acceptance, and uptake of emerging health interventions. Participants demonstrated openness to learning and positioned themselves as cultural and technological translators within their communities, roles that can enhance public understanding of complex science. Creative, entertainment-based communication approaches and endorsement from trusted community figures were seen as essential for effective outreach, particularly in contexts where formal education is not the primary channel of influence. Gender dynamics also emerged as a key consideration, highlighting the need for gender-sensitive strategies. Further research across diverse malaria-endemic settings is needed to capture stakeholder-specific perspectives and inform inclusive, context-sensitive strategies for informed decision-making on tools like GDMMs.

Declarations

Ethical considerations

Ethical approvals for this project were obtained from Ifakara Health Institute's Institutional Review Board (Protocol ID: IHI/IRB/No: 2 - 2021) and the Medical Research Coordinating Committee (MRCC) at the National Institute for Medical Research (Protocol ID: NIMR/HQ/R.8a/Vol.IX/3804). Permission to publish this study was obtained from NIMR, ref: BD.242/437/01C/98. For the participants that were below 18 years of age, their assent was obtained, together with consent from their guardians.

Availability of data and material

All data for this study will be available upon request.

Authors' contributions

GM was involved in study design, data collection, entry and analysis, interpretation of the results and writing the manuscript. MFF, FOO and MS, were involved in study design, supervision and critical revision of the manuscript. MS, RN, GM and SS were also involved in data collection and entry. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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