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Understanding the requirements and factors necessary for the acceptance of genetically modified mosquitoes as a potential malaria control tool in Ghana: a questionnaire survey

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Abstract. Genetically Modified Mosquitoes (GMMs) have been long proposed as a potential tool for malaria control. The challenges posed by current control strategies of bednet usage, Indoor Residual Spraying and larviciding, as well as the development of insecticide resistance to all the major classes of insecticides used against the vectors, have led to a renewed interest in the use of GMMs. Despite the achievements in developing GMMs, there are risks, benefits and public acceptance challenges that must be addressed in every country before any field trials and eventual releases can be undertaken. While various studies on attitudes to GMMs and open releases have been undertaken in some developed countries, this information is missing in Africa and other developing countries. We carried out a pilot questionnaire study, aimed at understanding the needs, requirements and factors necessary for the acceptance of GM mosquitoes as a potential malaria control tool in Ghana. The results showed that some individuals were open to accepting GMMs despite the perceived risks, and that whether or not they accepted them was not influenced by education, age, sex or religion. Public education and stakeholder consultations will be essential in obtaining public consent, before embarking on any malaria control using GMMs.

Keywords: Genetically Modified Mosquitoes (GMMs), Ghana, Public engagement

INTRODUCTION

Plasmodium falciparum malaria is a major mosquito-borne disease of public health importance, causing over 600,000 deaths a year, especially in children in sub-Saharan Africa (WHO, 2013). Various intervention and control strategies, such as the distribution of anti-malarial drugs, change in policy for more efficacious drugs against drug-resistant parasite strains (Koram *et al.,* 2005), and vector control strategies using Indoor Residual Spraying (Pluess *et al.*, 2010), Insecticide Treated Nets (Lengeler, 2004), and larviciding (Devine and Killeen, 2010) have been implemented with varying degrees of success. The continuous use of insecticides for control activities has however led to the emergence of resistance among the mosquito vectors (Ranson *et al.,* 2009). This calls for new methods and techniques for malaria vector control in endemic countries. The use of Genetically Modified Mosquitoes (GMMs) has been proposed as one such strategy, which requires the development of *P. falciparum* resistant mosquito strains that are capable of inhibiting parasite development and their transmission (Isaacs *et al.*, 2012).

The basic concept of genetic control of vector-borne diseases was proposed by Curtis (1968). Based on laboratory successes in the development of virus- and protozoan-resistant mosquito strains, the WHO/TDR identified 3 research aims that would have to be met before a genetic control strategy could be field tested (World Health Organization, 1991). These aims are: (i) the development of genetic engineering tools that could be used with malaria vectors; (ii) the identification of effector genes that could block parasite transmission; and (iii) the development of effective methods for driving these effector genes to fixation in natural vector populations. Based on these aims, several methods of germline transformation have been developed for use against at least three species of malaria mosquito vectors (Catteruccia *et al.*, 2000; Coates et al., 1998; Grossman *et al.*, 2001; Isaacs *et al.*, 2012). Genetic constructs that significantly reduce vector competence in experimental malaria models have also been developed (Capurro *et al.,* 2000; Ito *et al.,* 2002). Population

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replacement strategies for controlling transmission of mosquito-borne diseases call for the introgression of anti-pathogen effector genes into vector populations, thereby interrupting transmission. It is anticipated that these genes, if present at high enough frequencies, will impede transmission of the target pathogens and result in reduced human morbidity and mortality (James, 2005; Marshall and Taylor, 2009; Terenius *et al.*, 2008). For malaria control using GMMs, it has been suggested that control programs may not be effective if the efficiency of the engineered mosquito is less than 100% (Boete and Koella, 2002).

The achievements in developing GMMs, and the field releases that have been undertaken in the Cayman Islands (Harris *et al.,* 2011; 2012), Malaysia (Subramaniam *et al.*, 2012) and Brazil for the control of dengue, call for a focus on the ethical and sociological aspects governing the potential use of GM mosquitoes (Boëte and Beisel, 2013). Public acceptance is required - in the face of strong skepticism against genetically modified organisms (GMOs) in both developed and developing nations (Boëte and Beisel, 2013; Bohannon, 2002). Thus, there is the need to understand the public's views and incorporate their fears and aspirations into disease control strategies involving GMMs.

In developed countries, various studies on public attitudes to GMOs have been undertaken (Gaskell *et al.,* 2003; Macer et al., 1997; Martin and Tait, 1992; Masakazu and Macer, 2003; Moon and Balasubramanian, 2001; Ng *et al.*, 2000). Discussions and protocols have also been established for the public release of GMMs (Benedict *et al.,* 2008; Lavery et al., 2008; Mumford *et al.*, 2009). However, in disease endemic countries little investigation has been conducted (Marshall *et al.*, 2010a; Marshall *et al.,* 2010b). Some sub-Saharan African countries are gradually establishing regulatory mechanisms for the introduction and testing of GMOs. For example, the Government of Ghana in 2011 passed the Biosafety Act 831, 2011, which will enable Ghana to allow the application of biotechnology, including GMOs, in food crop production(http://173.1.128.235/assets/News_Photos/biosafetyact2011.pdf). Similar examples can be given in the form of the Zambian Biosafety Act 2007 (http://faolex.fao.org/docs/pdf/zam78318.pdf), and Kenya Biosafety Act 2009 (http://www.kenyalaw.org/klr/fileadmin/pdfdownloads/Acts/BiosafetyAct_No2of2009.pdf). In anticipating the needs for establishing protocols and biosafety mechanisms, initiatives such as the "African training course on biosafety for human health and the environment in relation to potential release of genetically modified disease vectors", supported by the WHO-TDR, have aimed at training individuals to provide information and support towards future initiatives involving the use of GMOs and genetically modified vectors (GMVs) in African countries. Thus, this pilot study aimed to understand the requirements and necessary factors for the acceptance of GM mosquitoes as a potential malaria control tool in Ghana.

METHODS AND MATERIALS

Study area. This study was conducted in and around the University of Ghana (UG) campus at Legon, Accra, Ghana. People from different backgrounds and ethnicity, and from all over Ghana, work at the UG or go there to study. As such, the UG campus and its surrounding communities have been selected as a study site, in order to maximize the possibilities of sampling the views of people from different backgrounds.

Study design and data collection. The survey was carried out using a modified questionnaire designed by Marshall et al., (2010b), and structured to include a short section on demographic information, knowledge on malaria, heredity, GMOs and GMMs. The questionnaire consisted of both closed and open ended questions to allow respondents to present their own perspectives beyond the coded categories provided (See Appendix 1). Since the University community is a literate population, the questionnaire was self-administered. Adequate instructions and information was provided to aid respondents to fill in the questionnaire correctly. Outside the university community, individuals with primary and secondary education, who had difficulties in reading, writing and understanding the questions, had the questionnaire administered to them by trained research assistants. However, the influence of the trained personnel was minimized by allowing them to select their own responses.

Participant selection. The population of the University of Ghana is roughly 30,000. However, considering the difficulties in assessing the population of the University of Ghana, together with that of the surrounding communities, the population size of the Accra Metropolitan Area (AMA), in which the study area falls, was used. Thus, based on a population of 1,695,136 individuals in the AMA (http://www.ghanadistricts.com/districts/?r=1&_=3&sa=3004), the minimum sample size of questionnaires that must be administered, based on an expected response rate of 85% and a 95% confidence interval, was determined to be 196. In total 210 questionnaires were administered for the study. The method of respondent selection varied according to the location, but in each case only individuals 18 years and above were selected for the study.

On the UG campus, the questionnaire was administered to 100 individuals. To obtain a representative sample, stratified random sampling was applied to the UG population. This was to enable us cover the UG population as thoroughly as possible, and avoid sampling only those people from a particular location. The population was classified into students, lecturers and non-teaching staff. The selection of student participants was further classified according to the main halls of residence on the university

campus. Thus, there were on average 14 participants in each category. Study participants in all the different classifications were selected by simple random sampling generated by computer-based programming, in Microsoft Excel®. For example, a generated sampling frame of 1, 3, 4, 8, etc. determined that the views of the first, third, fourth and eighth person encountered by the survey team were sampled. This continued until the number (14) required for each classification was reached. Outside the university campus, 110 respondents were selected randomly, using the same sampling frame.

Data Analysis. Collected data were entered and analyzed in Epi Info™ 7, a freely available software from the Centers for Disease Control and Prevention (CDC). Qualitative variables were presented as frequencies and percentages. Using the Kruskal-Wallis test, the influence of age group, sex, religion and education level on the decision to accept/refuse GMMs were estimated, with confidence limits of 95%. The Mantel-Haenszel test was used to estimate the common odds ratio and to test the significance of the overall degree of association between demographic variables and responses. Content analysis was conducted on the narrative data. Similar narratives were grouped together and representative narratives were selected for presentation to complement the quantitative findings for clarity and better understanding.

Ethical Considerations. Approval for this study was obtained from the Institutional Review Board of the Noguchi Memorial Institute for Medical Research, University of Ghana, Legon. Information regarding the study was given to each study respondent and written consent was obtained before the questionnaire was given out.

RESULTS

The response rates to the questionnaire were encouraging. On the university campus, out of 100 questionnaires given out, 98 (98%) were answered and returned. In the surrounding communities, 110 questionnaires were given out and 105 (95.5%) were returned.

The majority of study respondents (80.3%) were in the age category 18-29 years. Figure 1 shows the age distribution chart of the study participants. 60.8% of the respondents were male and 39.2% were female. 87.4% were Christian, and 9.6% were Muslim. The remaining 3% did not specify their religion. In the communities around the university campus, most of the respondents had some level of formal education: Basic Education (4.0%), Secondary Education (57.4%), Tertiary education (33.7%), and Post

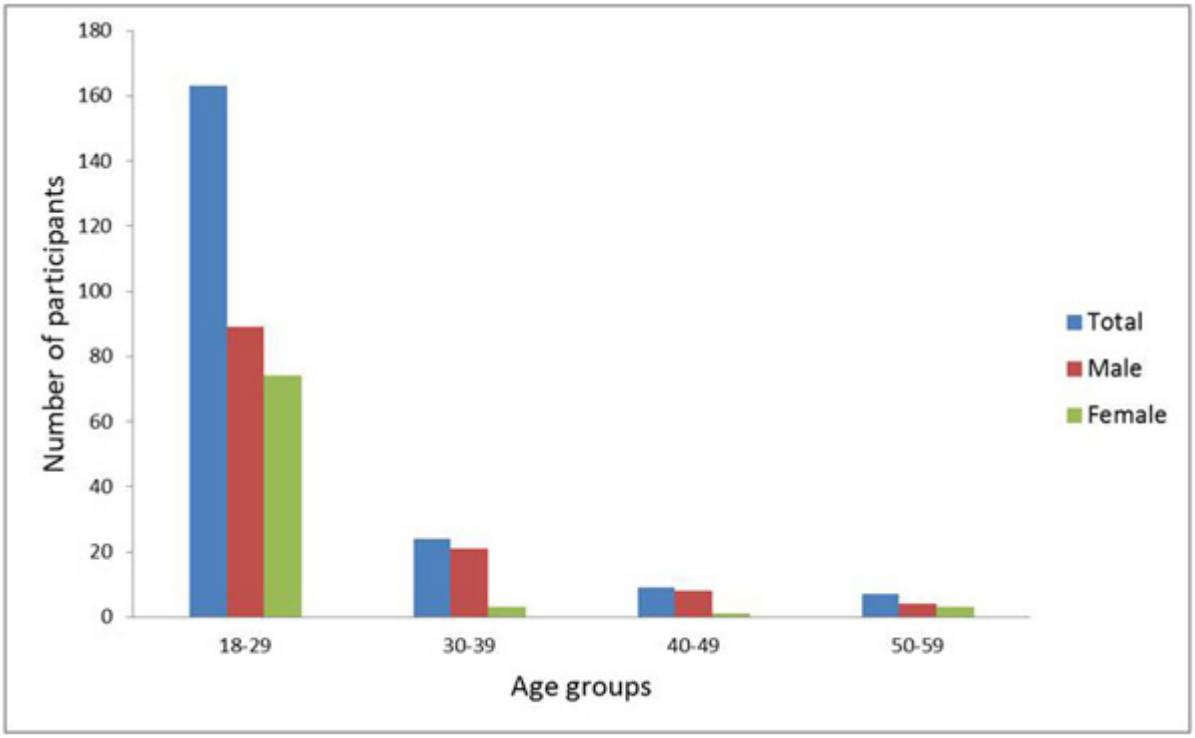

Figure 1. Age distribution of the overall study population. The age groupings of the study participants and the number of males or females in each group are shown.

Graduates (4.0%). Only one person did not have any formal education. On the university campus however, all individuals surveyed had tertiary education or above.

187 (92.1%) of the people surveyed correctly identified mosquitoes as the main cause of malaria. Other causes identified were rain/standing water, poor hygiene, pollution, cold weather and wind. Most study participants also knew the symptoms of malaria: listing fever, cold/shivering, vomiting, headache, loss of appetite and body-ache, listed in order of importance.

This study sought to determine the participants' understanding of heredity, selective breeding and GMOs. Thus, they were asked if they could identify the causes of similarity between parents and offspring. The causes identified in descending order of importance were genes, blood and God (Table 1). Mangoes, goats, chicken and oranges were identified as the most selectively bred organisms, whiles GM corn (45/195) was the number one identified GMO. Others also mentioned GM

Table 1 Reasons given by study participants, in University of Ghana (UG) campus and surrounding communities, for heredity and similarities between parents and offspring.

Reason for Heredity	UG Campus (%)	Outside Community (%)
Blood	3 (3.0)	35 (33.3)
Genes	95 (97.0)	82 (78.1)
God	10 (10.2)	8 (7.6)

mangoes, GM rice, GM chicken, GM plantain, GM millet and GM cotton as known GMOs. Of the 203 respondents 92 (45.3%) of respondents said they would accept GM foods, whilst 76 (37.4%) said they would not. The remaining 35 (17.2%) responded as either "Maybe" or "It depends on…". Generally, television (39.4%), radio (32.5%) and internet (42.9%) were the three main sources of information regarding GMOs (Table 2). However, the main sources of information varied between the two groups, with the UG Campus community mainly accessing information from the Internet (48%), newspapers

Table 2 Sources where study participants, from the University of Ghana (UG) campus and surrounding communities, got their information on Genetically Modified Organisms.

Sources of Information	UG Campus (%)	Outside Community (%)	Total (%)
Internet	47 (48.0)	40 (38.1)	87 (42.9)
Radio	19 (19.4)	47 (44.8)	66 (32.5)
TV	29 (29.6)	51 (48.6)	80 (39.4)
Newspaper	36 (36.7)	26 (24.8)	62 (30.5)
Friends	16 (16.3)	16 (15.2)	32 (15.8)

(36.7%) and television (29.6%), while people from the surrounding communities mainly got their information from the television (48.6%), radio (44.8%) and Internet (38.1%). 129 (63.6%) of the study respondents had never heard of GMMs.

The study respondents were asked to list their concerns regarding GMMs and varied concerns were mentioned. Only 48 people, all from the University community. provided narratives to this question. The concerns listed were danger to humans and the environment (22/48), resistance of GMMs to control measures (9/48), transmission of other diseases (3/48), ethical and religious issues (1/48), and the effectiveness of the technology (13/48). These positions were supported by the following example narratives:

-Long term widespread ecological implications unknown, their populations may grow to unmanageable levels, malaria parasites may adapt to the new host keeping the disease alive in a form for which there is no treatment. (38 years old, male university worker)

-How certain is this going to be successful, will there be no adverse consequences to both human and ecology? (26 years old, male university student).

-A genetic modification can yield a suitable trait alright but can also cause another unknown unfavourable trait, so all possible options must be reviewed (19 years old, male university student).

-What is the chance of the GM mosquitoes spreading the transgenic resistance to the wild? (23 years old, female university student).

-It should be carried on condition it can really reduce the rate of transmission of malaria (22 years old, female university student).

In addition to these, the respondents were asked to rank some pre-identified concerns. Generally, 45.1% were very concerned about GMMs, 22.7% did not know, 21.3% were a little worried, and 10.9% were not worried about GMMs. The cost of development and implementation was the least significant of the concerns, whiles the continued transmission of malaria by GMMs was the most important concerns (Figure 2).

Participants were also asked to rank some identified requirements to be met before accepting GM mosquitoes in terms of importance (with the responses 'very important', 'moderately important', 'not important' and 'don't know'). In general, 54.8% of respondents considered it to be 'very important' for certain requirements to be met before accepting GMMs in Ghana, while 28.0% considered the requirements to be 'moderately important', 9.3% considered the requirements to be of no importance and 7.9% did not know. The requirements considered to be very important were: Evidence from

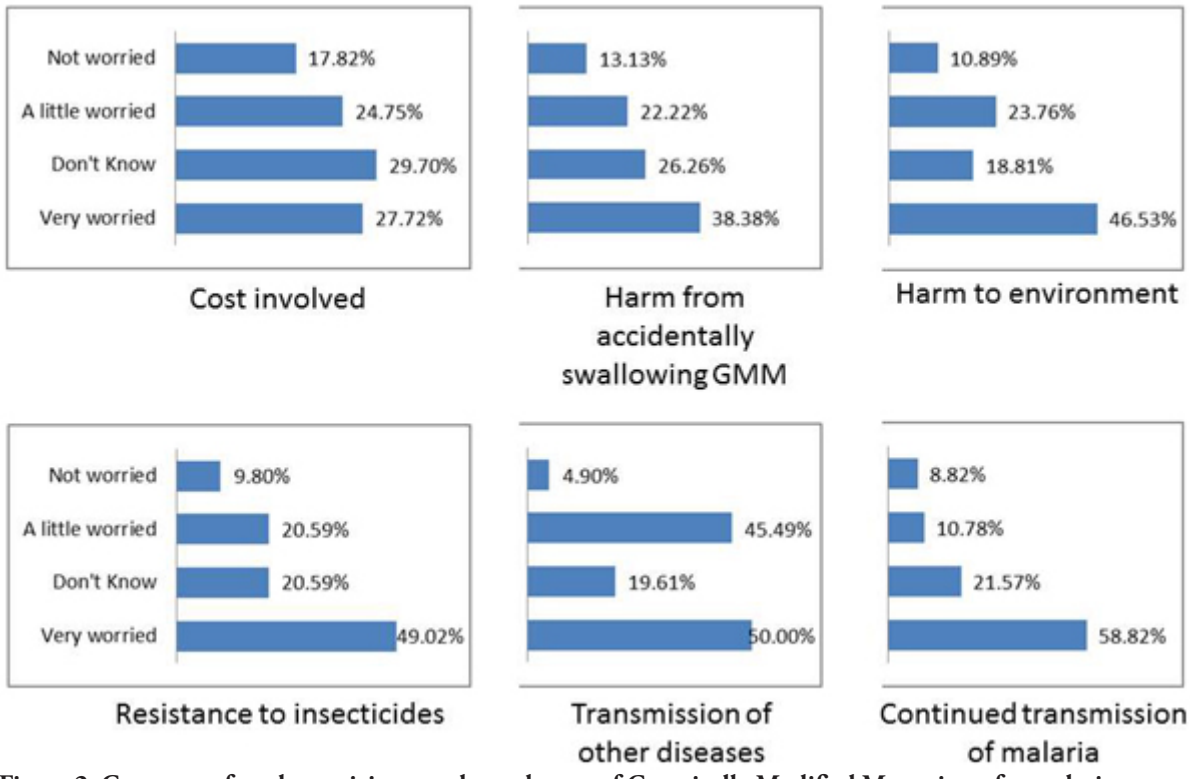

Figure 2. Concerns of study participants, about the use of Genetically Modified Mosquitoes for malaria control in Ghana. Each concern is represented by a graph, shows the percentage of respondents who are either "not worried', "a little worried" or "very worried".

laboratory experiments and successful trials (116/198), provision of safeguarding measures against adverse effects (112/198), extensive public awareness and education on how GMMs reduce malaria (106/198), dialogue and approval by the majority of the community (96/198), and ability to abort the project (68/198).

Table 3 Sources that study participants, from the University of Ghana (UG) Campus and surrounding communities, will trust for information on Genetically Modified Mosquitoes.

Source of Information	UG Campus (%)	Outside Community (%)	Total (%)
Ghana Government	18 (18.4)	54 (51.4)	72 (35.5)
Foreign Exporter	2 (2.0)	2 (1.9)	4 (2.0)
Religious Bodies	6 (6.1)	11 (10.5)	17 (8.4)
Scientific Organization	80 (81.6)	62 (59.1)	142 (70.0)
United Nations	49 (50)	41 (39.1)	90 (44.3)
Local Media	10 (10.2)	22 (21.0)	32 (15.8)

In general, manyrespondents were 'very worried' (45.1%) or a little worried' (21.3%) about the possible consequencesofGMMssuchasGMMscontinuingtotransmit malaria, transmitting other diseases, becoming resistant to insecticides, or causing harm to the environment. This position was is illustrated by the narrative below:

-If it is acceptable, ethical issues resolved, well equip lab for GM mosquito, safe testing of GM mosquito, approved by testing using biosafety guidelines in Ghana. (30 years old, male postgraduate student).

The three main sources that respondents would trust for information regarding GMMs were local scientific organizations (70%), the United Nations (44.3%) and the Ghanaian government (35.5%) (Table 3). However, only 15.8% and 8.4% of people surveyed said they would trust the local media and religious groups, respectively, for information.

There were mixed reactions to the use of GMMs for malaria control. Whiles 56/102 community respondents believed that GMMs would continue to transmit malaria, 76/89 UG campus respondents disagreed with that view. 65/101 community respondents agreed that bednets and insecticides have not been effective against malaria control, and so GMMs will be no different, while 52/88 UG campus respondents disagreed. The majority of people in both groups

Table 4 Responses of study participants, from the University of Ghana (UG) campus and surrounding communities, to some statements about Genetically Modified Mosquitoes. The values presented are the number of people who "agree" or "disagree" with each statement.

Statement	UG Campus			Outside Communities		
	Agree	Disagree	don't know	Agree	Disagree	don't know
A mosquito is a mosquito - modified or unmodified it will always transmit malaria	11	67	11	56	20	26
If the United Nations tells me that GM mosquitoes will be good for my country, I will believe them	52	25	10	52	27	23
Malaria is worse than any negative consequences that the GM mosquitoes could have	19	36	31	52	17	33
If GM mosquitoes could have unknown risks, then they shouldn't be released.	69	16	1	77	14	12
Bednets and insecticides have barely reduced the number of malaria cases in Africa. GM mosquitoes will not be any different.	18	52	18	65	23	13
We have tried to kill mosquitoes and it has not worked. It is better to modify them so they can't transmit disease.	61	12	16	66	20	15

however agreed that "if there are unknown risks to GMMs, then they should not be used" and they also agreed that "it is better to modify mosquitoes so they do not transmit malaria" (Table 4). When asked whether they would approve the release of GMMs, 27/145 (18.6%) of participants said they would 'never' agree to a release under any circumstance, 82/145 (56.6%) said 'no' to a release, and 36/145 (24.8%) said 'yes' to a release (Table 5). The differences were not significant (χ^2 = 0.15, P value = 0.70) between those who agreed and those who disagreed, and the odds of education influencing the decision was around 1 (range 0.98-1.28) in all categories. Similarly, there was no significant difference between those who agreed or disagreed with trying GMMs based on their age, sex or religion. The results were also not statistically significant when the results of the two populations were compared.

DISCUSSION

The findings presented in this study represent those of a subset of the Ghanaian population. However, they do provide us with an idea of what to expect in the decision to employ the use of GMMs for malaria control in Ghana. The study participants responded to the questionnaire with enthusiasm, and appreciated the purpose of the study.

This study set out to identify and understand the needs and required factors for the acceptance of GMMs as a potential malaria control tool in Ghana. This is the first time that the questionnaire developed by Marshall and colleagues (2010) has been adapted to study respondents' views on GMMs for malaria control in Ghana. Whereas participants in the (Marshall *et al.*, 2010a) Malian study were interviewed using the questionnaire, our study adopted a self-administering technique, where respondents filled the questions at their own pace and convenience to reduce the influence of the interviewer on the responses. For example Marshall and colleagues (Marshall *et al.,* 2010a) reported biases towards council members, decision-makers and men, who were selected by recommendation, and these biases were significantly reduced in the present study using a random sampling technique to select our respondents. We did, however, face the challenge of people not answering all questions. Findings reported here cannot be generalized as they represent the views of mostly educated urban dwellers. Further, we did not determine the nature of the educational background (science or non-science) of the people surveyed, nor the impact this could have on perception and acceptance of GMMs.

This pilot survey targeted an educated community, and the influence of this subset of the population may be substantial in sensitive cases such as the use of genetic engineering in the development of Ghana. Thus, their view towards the use of GMMs was paramount. The results revealed some differences between the responses from

Table 5 Responses of study participants, from the University of Ghana (UG) Campus and surrounding communities, to releasing Genetically Modified Mosquitoes for malaria control in Ghana

Response	UG Campus (%)	Outside communities (%)	Total (%)
Never	14 (25.5)	13 (14.4)	27 (18.6)
No	34 (61.8)	48 (67.8)	82 (56.6)
Yes	7 (12.7)	29 (32.2)	36 (24.8)

the UG campus population and the outside community, however the general response to approving a release of GMMs was not significantly different between these two groups. Thus, education informed the level of understanding, but did not influence the likelihood of a respondent making the decision to accept GMMs. Likewise, age, sex and religion had no influence on the decision to accept GMMs. Macer and colleagues (1997) reported similar observations in Japan and New Zealand, and found that level of education does not correlate with the acceptance of genetic engineering. This goes to show the complexity of the issues, and the individual's reliance on intuitive risk judgments or 'risk perceptions' (Slovic, 1987) when making decisions regarding GMOs.

The introduction of a new technology must face the public's perceptions about the risks and benefits associated with its use (Goyal and Gurtoo, 2011). The conflicting results observed in this study may point to a lack of understanding of the concepts of genetic modification. Whilst 56.6% of respondents said 'no' to a GMM release for malaria control, 66.8% agreed that it is better to modify mosquitoes so that they cannot transmit malaria. Of course there were also individuals who were totally opposed to the idea of GMMs. A populations' risk benefit analysis of a technology should inform its use and application. It has been suggested that the consequences of applying a new technology is related to the perceived risks or benefits of applications (Frewer and Shepherd, 1995). Also, some of the concerns identified point to a lack of understanding of the concept behind the use of GMMs for malaria control. Thus, for GMMs to be accepted, education about the risks and benefits will be very important, to enable people to make informed decisions.

The majority of the people surveyed got their information about GMOs from the internet, television or the radio. While the media has a significant impact on public opinion formation in cases where public knowledge is low (Ten, 2005), this survey showed that the media is not a very trusted source of information for most respondents when it comes to GMMs. While the reasons for this were not determined by the study, it has been proposed that scientists tend to present issues objectively, albeit in more technical terms, than the media which is usually attracted to shocking and scandalous headlines (Goyal and Gurtoo, 2011). In their recent paper, Goyal and Gurtoo (2011) suggested that the media reportage on GMOs must be calm and objective, and not stoke public sentiment and make people emotionally charged. Nonetheless, the responsibility for the trust of GMMs among respondents rests with scientists and the government. Volti (2010) suggested that the credibility of the risk regulators is likely to be an important factor in public risk acceptance. It has been argued that the failure of scientists and administrators to regulate the technology adequately will lead to a rapid loss of public trust (Marris, 2001). In the light of the responses presented in this study, further studies must look at the roles of various stakeholders in accepting GMOs in Ghana. These future studies should encompass analysis and comparison of data from urban and rural areas, look at the acceptability of GMMs among decision makers, and the influence of educational background (science versus non-science) on perceived acceptability. The questionnaire will have to be redesigned to better estimate the important factors identified in this present study, while taking into consideration the social, ethical, language and cultural barriers.

CONCLUSION

In summary, we have explored some factors that may contribute to the acceptance of GMMs as a potential malaria control tool in Ghana. While some individuals questioned were open to accepting GMMs despite the perceived risks, the decision to accept them was not influenced by education, age, sex or religion. Public education and stakeholder consultations will be essential in obtaining public consent before embarking on any malaria control attempts using GMMs. This study was a pilot survey targeting a literate community, and further studies are required, especially those targeting individuals with more limited educational backgrounds and less information on GMOs. For these individuals, the questionnaire and concepts of genetic modification must be interpreted into local languages, and appropriate terms coined for technical words such as genes and genetically modified mosquitoes. This will enable people to better understand the concepts and notions of genetic modification. Until the social and ethical issues concerning the use and release of GMMs for malaria control have been fully addressed, the application of accepted classical methods of vector control and malaria chemotherapy should be intensified to reduce the present malaria burden.

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REFERENCES

Benedict, M., D'Abbs, P., Dobson, S., Gottlieb, M., Harrington, L., Higgs, S., James, A., James, S., Knols, B., Lavery, J., O'Neill, S., Scott, T., Takken, W. and Touré, Y. 2008. Guidance for contained field trials of vector mosquitoes engineered to contain a gene drive system: recommendations of a scientific working group. *Vector-Borne Zoonotic Diseases* 8: 127-166.

Boete, C. and Koella, J. 2002. A theoretical approach to predicting the success of genetic manipulation of malaria mosquitoes in malaria control. *Malaria Journal* 1:3.

Boëte, C., Beisel, U., 2013. Transgenic Mosquitoes for Malaria Control: From the Bench to the Public Opinion Survey, in: Manguin, S. (Ed.), Anopheles mosquitoes - New insights into malaria vectors. InTech.

Bohannon, J. 2002. Zambia rejects GM corn on scientists' advice. *Science* 298: 1153-1154.

Capurro, M.d.L., Coleman, J., Beerntsen, B.T., Myles, K.M., Olson, K.E., Rocha, E., Krettli, A.U. and James, A.A. 2000. Virus-expressed, recombinant single-chain antibody blocks sporozoite infection of salivary glands in Plasmodium gallinaceum-infected *Aedes aegypti.* American *Journal of Tropical Medicine and Hygiene* 62: 427-433.

Catteruccia, F., Nolan, T., Loukeris, T.G., Blass, C., Savakis, C., Kafatos, F.C.and Crisanti, A. 2000. Stable germline transformation of the malaria mosquito *Anopheles stephensi. Nature* 405: 959-962.

Coates, C.J., Jasinskiene, N., Miyashiro, L. and James, A.A. 1998. Mariner transposition and transformation of the yellow fever mosquito, *Aedes aegypti*. Proceedings of the *National Academy of Science U.S.A.* 95: 3748.

Curtis, C.F. 1968. Possible use of translocations to fix desirable genes in insect pest populations. *Nature 2*18: 368-369.

Devine, G.J. and Killeen, G.F. 2010. The potential of a new larviciding method for the control of malaria vectors. *Malaria Journal* 9: 142.

Frewer, L.J. and Shepherd, R. 1995. Ethical concerns and risk perceptions associated with different applications of genetic engineering: interrelationships with the perceived need for regulation of the technology. *Agriculture and Human Values* 12: 48-57.

Gaskell, G., Allum, N. and Stares, S. 2003. Europeans and biotechnology in 2002: Eurobarometer 58.0. European Commission Directorate-General, London.

Goyal, P. and Gurtoo, S. 2011. Factors Influencing Public Perception: Genetically Modified Organisms. *GMO Biosafety Research* 2: 1-11.

Grossman, G.L., Rafferty, C.S., Clayton, J.R., Stevens, T.K., Mukabayire, O. and Benedict, M.Q. 2001. Germline transformation of the malaria vector, *Anopheles gambiae*, with the *piggyBac* transposable element. *Insect Molecular Biology* 10: 597-604.

Harris, A.F., McKemey, A.R., Nimmo, D., Curtis, Z., Black, I., Morgan, S.A., Oviedo, M.N., Lacroix, R., Naish, N., Morrison, N.I., Collado, A., Stevenson, J., Scaife, S., Dafa'alla, T., Fu, G., Phillips, C., Miles, A., Raduan, N., Kelly, N., Beech, C., Donnelly, C.A., Petrie, W.D. and Alphey, L. 2012. Successful suppression of a field mosquito population by sustained release of engineered male mosquitoes. *Nature Biotechnology* 30: 828-830.

Harris, A.F., Nimmo, D., McKemey, A.R., Kelly, N., Scaife, S., Donnelly, C.A., Beech, C., Petrie, W.D. and Alphey, L. 2011. Field performance of engineered male mosquitoes. *Nature Biotechnology* 29: 1034-1037.

Isaacs, A.T., Jasinskiene, N., Tretiakov, M., Thiery, I., Zettor, A., Bourgouin, C. and James, A.A. 2012. Transgenic *Anopheles stephensi* coexpressing single-chain antibodies resist Plasmodium falciparum development. Proceedings of the *National Academy of Sciences* 109: E1922-E1930.

Ito, J., Ghosh, A., Moreira, L.A., Wimmer, E.A. and Jacobs-Lorena, M. 2002. Transgenic anopheline mosquitoes impaired in transmission of a malaria parasite. *Nature* 417: 452-455.

James, A.A. 2005. Gene drive systems in mosquitoes: Rules of the road. *Trends in Parasitology* 21: 64-67.

Koram, K.A., Abuaku, B., Duah, N. and Quashie, N. 2005. Comparative efficacy of antimalarial drugs including ACTs in the treatment of uncomplicated malaria among children under 5 years in Ghana. *Acta Tropica* 95: 194-203.

Lavery, J., Harrington, L. and Scott, T. 2008. Ethical, social and cultural considerations for site selection for research with genetically modified mosquitoes. *American Journal of Tropical Medicine and Hygiene* 79: 312-318.

Lengeler, C. 2004. Insecticide-treated bed nets and curtains for preventing malaria. *Cochrane Database Systematic Review* 2: CD000363.

Macer, D., Howard, B., Harman, N., Kamada, H. and Macer, N. 1997. Attitudes to biotechnology in Japan and New Zealand in 1997, with international comparisons. *Eubios Journal of Asian and International Bioethics* 7: 137-151.

Marris, C. 2001. Public views GMOs: deconstructing the myths. *EMBO reports* 2: 545-548.

Marshall, J., Toure, M., Traore, M., Famenini, S. and Taylor, C. 2010a. Perspectives of people in Mali toward genetically-modified mosquitoes for malaria control. *Malaria Journal* 9: 128.

Marshall, J.M. and Taylor, C.E. 2009. Malaria control with transgenic mosquitoes. *PLoS Medecine* 6: e20.

Marshall, J.M., Touré, M.B., Traore, M.M. and Taylor, C.E. 2010b. Towards a quantitative assessment of public attitudes to transgenic mosquitoes: Questions based on a qualitative survey in Mali. *Asia-Pacific Journal of Molecular Biology & Biotechnology* 18: 251-273.

Martin, S. and Tait, J. 1992. Attitudes of selected public groups in the UK to biotechnology, in: Durant, J. (Ed.), Biotechnology in Public: a Review of Recent Research. Science Museum, London, UK, pp. 28-41.

Masakazu, I. and Macer, D. 2003. Attitudes to biotechnology in Japan in 2003. E*ubios Journal of Asian and International Bioethics 1*3: 78-90.

Moon, W. and Balasubramanian, S.K. 2001. Public Perceptions and Willingness-To-Pay A Premium for Non-GM Foods in the US and UK. *AgBioForum* 3-4: 221-231.

Mumford, J., Quinlan, M.M., Beech, C., Alphey, L., Bayard, V., Capurro, M.L., Kittayapong, P., Knight, J.D., Marrelli, M.T., Ombongi, K., Ramsey, J.M. and Reuben, R. 2009. MosqGuide: A project to develop best practice guidance for the deployment of innovative genetic vector control strategies for malaria and dengue. *Asia-Pacific Journal of Molecular Biology & Biotechnology* 17: 93-95.

Ng, M., Takeda, C., Watanabe, T. and Macer, D. 2000. Attitudes of the public and scientists to biotechnology in Japan at the start of 2000. *Eubios Journal of Asian and International Bioethics 1*0: 106-113.

Pluess, B., Tanser, F.C., Lengeler, C. and Sharp, B.L. 2010. Indoor residual spraying for preventing malaria. Cochrane Database Systematic Review 4: CD006657.

Ranson, H., Abdallah, H., Badolo, A., Guelbeogo, W.M., Kerah-Hinzoumbé, C., Yangalbé-Kalnoné, E., Sagnon, N., Simard, F. and Coetzee, M. 2009. Insecticide resistance in Anopheles gambiae: data from the first year of a multi-country study highlight the extent of the problem. Malaria Journal 8: 299.

Slovic, P. 1987. Perception of risk. Science 236: 280-285.

Subramaniam, T.S.S., Lee, H.L., Ahmad, N.W. and Murad, S. 2012. Genetically modified mosquito: The Malaysian public engagement experience. *Biotechnology Journal* 7: 1323-1327.

Ten, E.T.A. 2005. The media and public opinion on genetics and biotechnology: mirrors, windows, or walls? *Public Understanding of Science* 14: 305-316.

Terenius, O., Marinotti, O., Sieglaff, D. and James, A.A. 2008. Molecular genetic manipulation of vector mosquitoes. Cell Host Microbe 4: 417-423.

Volti, R. 2010. Society and Technological Change, In Medical and Biological Technologies. Worth Publishers, USA, pp. 233-278.

WHO, 1991. Prospects for malaria control by genetic manipulation of its vectors. World Health Organization, Geneva, Switzerland.

WHO, 2013. Malaria. Fact sheet N°94. World Health Organization, Geneva, Switzerland.

Appendix 1. Understanding the Public Views to the Potential Use of Genetically Modified Mosquitoes as a Malaria Control Tool in Ghana. example of the questionnaire used for the reported study.

DEMOGRAPHIC INFORMATION

No.	Question	Response	Code
1	Age		.....
2	Gender	Male Female	1 2
3	Education	No education Primary JHS SHS Post secondary Other, specify_____	1 2 3 4 5 99
4	Religion	Muslim Christian Traditional No religion Other, specify_____	1 2 3 4 99
		MALARIA	
5	Malaria is a common disease in Africa. Which of the following do you think can cause malaria? (You may choose more than 1 option)	Mosquitoes Pollution Cold Weather Wind Poor hygiene Sweet foods / Sugar Oily foods / peanuts Rain/ Standing water Eggs Don't know Other, specify_____	1 2 3 4 5 6 7 8 9 10 99
6	Which of the following symptoms would you associate with malaria? (You may choose more than 1 option)	Fever/hot body Body-ache Headache Vomiting Cold/shivering Loss of appetite Other, specify_____	1 2 3 4 5 6 99
7	Do you know of any malaria control measures? Please list them		

HEREDITY AND GENETICALLY MODIFIED ORGANISMS			
8	In nature it is common for offspring to resemble their parents – for example, a daughter may resemble her mother in some ways and her father in some other ways. What do you consider to be the reason for this/these traits? (You may choose more than 1 option)	Blood Affection God Genes/DNA Don't know Other, specify_____	1 2 3 4 5 99
9	Which animals / vegetables or fruits are selectively bred/grown in your community? (You may choose more than 1 option)	Goats Cereal crops Chicken Cow Mangoes Sheep Oranges Don't know Other, specify_____	1 2 3 4 5 6 7 8 99
10	Which genetically modified (GM) organisms do you know of? Please List them.	1. 2. 3. 4. 5.	
11	Where did you hear/read of this/these GM organisms? (You may choose more than 1 option)	Radio Television Journal/Newspaper Internet Conversation with a friend Other, specify_____	1 2 3 4 5 99
12	Would you accept GM foods? Why?		
13	Have you ever heard of GM mosquitoes?	Yes No	1 2
GENETICALLY MODIFIED MOSQUITOES			
14	Do you have any concerns regarding the use of GM mosquitoes? Please list them.	1. 2. 3. 4. 5.	
15	Which requirements would you like to see in place before accepting GM mosquitoes in Ghana?	1. 2. 3. 4. 5. 6	

16	Which organization would you trust for information about GM mosquitoes?	Ghanaian Government Foreign Exporter Scientific Organization Religious bodies Local medical specialists United Nations Organization Other, specify_____	1 2 3 4 5 6 99
17	Under what circumstances would you consider it acceptable to release GM mosquitoes in Ghana? 1= Yes; 2= No; 3= Never	-If the United Nations said they were safe and help reduce the number of malaria cases -If the Ghanaian government said they were safe and help reduce the number of cases -If they were approved by a majority in my community -If I saw the results of a successful trial in a nearby community -If I saw the results of a successful laboratory experience -If it was possible to stop the project -Always. I approve of the release of GM mosquitoes unconditionally -Never. I don't approve releasing GM mosquitoes under any circumstances	....
18	For each of the following statements regarding GM mosquitoes, please indicate, to what extent you agree/ disagree. 1= strongly agree 2= agree 3=don't know 4=disagree 5=strongly disagree	-A mosquito is a mosquito – modified or unmodified it will always transmit malaria. -If the United Nations tells me that GM mosquitoes will be good for my country, I will believe them. -Malaria is far worse than any negative consequences that the GM mosquitoes could have. -If GM mosquitoes could have unknown risks, then they shouldn't be released. -Bed nets and Insecticides have barely reduced the number of malaria cases in Africa. GM mosquitoes will not be any different. -We have tried to kill mosquitoes and it has not worked. It is better to modify them so they can't transmit disease.	....

What are your personal views/comments regarding GM mosquitoes?