organization have expressed interest in joining this COST action. To date, COST Action FP0905 is one of the top EU actions in terms of number of participating EU and non-EU countries. By integration of all these country positions, COST Action FP0905 will generate important benefits and synergies. This collaboration will be fundamental to building scientific consensus on safety issues, assisting in policy-making efforts and enabling the scientific community to respond to public concerns in a responsible way, with particular regard to socioeconomic implications, environmental impacts and other biosafety issues surrounding plantations of GM trees.

Considering that the "mission of the COST is to strengthen Europe in scientific and technical research through the support of European cooperation and interaction between research" (http://www.cost.esf.org/), the implementation of this action is an excellent instrument to stimulate a European-wide exchange and improvement of scientific knowledge on biosafety of GM trees.

As the first COST action on GM trees, it is timely, relevant and innovative, especially in the context of the existing debate in Europe on cultivation and commercialization of GM plants, given the increasing role that engineered crops and trees are seen to have in mitigating climate change and environmental phytoremediation. A wide exchange of scientific knowledge has now been initiated globally that provides a unique opportunity to develop a common scientific baseline for biosafety research and development of engineered trees. Parties interested in joining or taking part in the COST action FP0905 activities should e-mail the chair of the action, Cristina Vettori (cristina.vettori@cnr.it).

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Factors influencing agbiotech adoption and development in sub-Saharan Africa

To the Editor:

Despite the technical knowledge available for improving food security in sub-Saharan Africa (SSA), only three African countries (South Africa, Egypt and Burkina Faso) have commercialized biotech crops to date[1]. An important step toward improving agbiotech development and genetically modified (GM) crop adoption is to understand the factors that affect the transition of new agbiotech products from the product development stage, through commercialization to the hands of farmers and ultimate consumption by the population. As part of a broader study on a social audit preparation for the Water Efficient Maize for Africa Project, we conducted 91 interviews with agbiotech stakeholders from a diverse range of groups within five SSA countries (**Supplementary Methods**). Analysis of the recordings of these interviews revealed four recurring factors that appear to influence agbiotech development in SSA: communication, culture and religion, capacity building and commercialization (**Fig. 1**). We expand in more detail on these factors below.

The first issue mentioned in the interviews is that poor communication is affecting agbiotech adoption. The majority of stakeholders interviewed identified a limited understanding of GM crops by the public as a major challenge to improving public perception of the technology for successful development and adoption of agbiotech in SSA. Indeed, one stakeholder stated, "My understanding is that a number of people, including politicians and some decision makers, do not know really what GM is." Elitism in reporting and ineffective and inaccurate communication by the media and other stakeholder groups were described as barriers to appropriate information sharing and informed public perception.

Stakeholders from the media and research institutions found information sharing with grassroots communities to be elitist. One study participant from the media suggested that the modes of communication used may be "a little bit above the common man." A need for "barefoot extension officers" was suggested by one government official as was the usefulness of grassroots approaches, to ensure the lay person is well informed about the multiple facets of agbiotech products and issues surrounding GM technology.

Similarly, it was mentioned by a research officer that the producers of knowledge around the technology, the scientists, may not be communicating information effectively: "...probably scientists will not be good communicators when it comes to talking or playing with farmer's psychology."

The impact of negative perceptions shared about agbiotech among stakeholders was discussed mainly by government regulatory and biotech awareness organizations, who considered anti-GM crops lobbyists and some nongovernment organizations (NGOs) as major challengers to the acceptance of agbiotech in SSA. Environmentalists and stakeholders from anti-GM crops groups confirmed this, expressing their concerns that the introduction of agbiotech will threaten the survival of indigenous crops and affect biodiversity. Other stakeholders drew attention to the fact that anti-GM crops groups have the capacity for widespread dissemination of information at the grassroots level and can spread misinformation and create extensive public concern and distrust for agbiotech initiatives.

Another unifying concern among interviewees was the issue of capacity building. Agbiotech stakeholders, particularly from regulatory institutions in Kenya, Uganda, Mozambique and Tanzania,

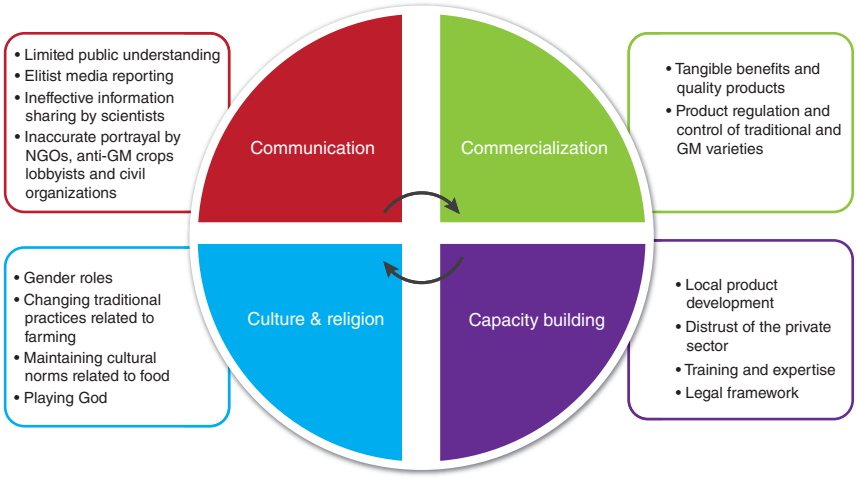

Figure 1 Factors in the adoption and development of agbiotech in sub-Saharan Africa.

identified inadequate training and expertise as a major constraint to the development of agbiotech in SSA. They called for an increase in the number of individuals with degrees at the graduate and post-graduate levels, and with trained expertise in biotechnological applications.

Stakeholders, particularly from regulatory institutions, farmer organizations, media and NGOs commented that the lack of a sufficient biosafety framework could hamper the development and adoption of agbiotech in many SSA countries. Several African countries have not developed biosafety regulations to govern agbiotech. For example, Uganda and Mozambique do not have appropriate laws to govern the commercialization of GM crops.

Study participants from research institutes and seed industries discussed the importance of developing agbiotech products locally to ensure adoption by the population. One participant stated, "A big problem I have with Americans [and] Europeans in terms of all those innovations, [it] happens up there and then they bring the final product here." From this viewpoint, each new GM variety that is introduced is often perceived as "a project that is being imposed on them." In contrast, a product developed within the country is considered "…more acceptable because it is being introduced by the local people." Several participants saw the introduction of foreign biotechnologies as a means of control over the local people, whereby agbiotech was considered to be "… some effort by the Western world to come and take advantage of poor Africans."

Stakeholders from seed companies, NGOs and agricultural research institutes commented on stakeholders' distrust of the private sector, particularly multinational companies, as a factor in resistance to agbiotech adoption. They spoke of concerns about the threat to food sovereignty and independence. One stakeholder asked, "How does that [agbiotech] affect their [the country's] right to food, their rights to food sovereignty, and will it be a war of farmers *vis-à-vis* multinationals?" On the other hand, stakeholders acknowledged the value that private companies and donors bring to bear in areas, such as agbiotech, in terms of technological expertise and experience.

A third common theme is the importance of cultural and religious issues. Several stakeholders, mainly from farmers' organizations, identified the roles of women and men in agriculture as important factors for the development of agbiotech. Although the substantial contribution of women to agriculture in SSA is seldom acknowledged and men are often at the forefront of decision making, women were repeatedly referred to by stakeholders interviewed as the primary agriculturalists, whereas men are associated with secondary work of buying and selling agricultural products. One stakeholder stated, "There is also the issue of most farmers being women, and yet women being limited in decision making. So that limits the technology uptake…The men are the ones who decide whether you should open a new piece of land or whether you should take up new things into the family." Stakeholders indicated that for agbiotech to be successful, changes must be made to the current system to involve women in leading the decision-making process concerning agbiotech and ensure that GM products reach women farmers and consumers.

We also learned from the interviewees that current GM products may not fit into existing traditional agricultural practices. There is public perception of current GM crops "…changing their [people's] practices and changing their culture…." Concerns exist about modern agbiotech practices and business models adversely affecting traditional seed systems, including seed selection and breeding, seed sharing and storage, leading to a loss of indigenous varieties. Participants, mainly from farmers' associations and NGOs, were particularly emphatic about this concern. One stakeholder stated, "Some people believe this [GM crop] is going to overshadow traditional crops, or probably kill them and render them extinct." Another stakeholder drew attention to the fear that exists about the irreversibility of using these technologies: "So we may be able to say that by helping the person you may actually be harming perhaps their traditional farming methods that have kept them alive. Now you change it and lose their knowledge and certainly they can't go back to where they were." Nonetheless, some stakeholders hoped that new agbiotech approaches will be adaptable to traditional seed systems and provide safeguards to traditional seeds that have been cultivated over the years.

The interviews also revealed that the conformity of GM crops to culturally established norms is important for the adoption of agbiotech in SSA. As one participant stated, "I think the final product has somehow to relate to the local use and the way that it is consumed or in the way that it is marketed." Stakeholders from organizations that work closely with small-scale farmers, such as extension staff, NGOs and farmers' associations, expressed views that failure to produce culturally appropriate products, in terms of appearance, taste, texture, processing qualities and storability may ultimately result in low uptake of the technology.

Participants described perceptions of many Africans regarding agbiotech as unnatural and interfering with nature. In terms of the strong adherence of people in many parts of SSA to their religion, participants commented that modern agbiotech and genetic engineering may be regarded by some people as taking on the role of God. One participant from a seed trade association said, "People get worried and say if you are interfering with what God made, then you are interfering with my inner feelings already."

A last unifying aspect of interviewee feedback related to issues surrounding commercialization of GM crops. Farmers and stakeholders from farmers' associations, seed companies, government regulatory

organizations and agricultural extension services identified the need to see some sort of benefit (either in yield, health outcomes or other tangible advantages) as a key factor in adoption. In addition, one stakeholder identified perceived quality of the GM products as having greater importance than affordability as a deciding factor for adoption: "If the [agricultural] technology is more efficient, it will be adopted. Farmers are not much sentimental."

One other aspect of considerable concern was difficulties associated with maintaining exclusivity between GM and non-GM crop plots, and the potential for admixture, outcrossing and a loss of local seed varieties. A labeling system to distinguish agbiotech products in a market setting was suggested by some stakeholders from academia and the seed industry to protect against product counterfeiting and ensure compliance with biosafety regulations.

In summary, interviews of 91 agbiotech stakeholders in five SSA countries have identified four prominent factors that influence the development and adoption of agbiotech products and technology in the region. The two most prominent of these factors are communication, and culture and religion[2]. The factors that arise within these themes may play more critical roles in agbiotech development and uptake in SSA than was previously thought. According to the stakeholders interviewed, the requirements of accurate, effective information sharing about agbiotech from reliable sources, for successful development and adoption, have not been upheld in SSA. Stakeholders explained that there is a great deal of controversy about the opportunities and risks posed by agbiotech, owing to a lack of, or insufficient access to, reliable information.

The use of agbiotech products and technologies that attempt to change traditional agricultural practices and food production norms in SSA may face great resistance. On the other hand, products that can complement local food production and consumption practices and involve primary agriculturalists, especially women, in decision making around the technologies, are likely to be more effective. Women are responsible for up to 70% of food production in Africa[3], a percentage that is likely much higher in rural areas. The establishment of biosafety regulations and the provision of high-quality products with tangible benefits are also likely to facilitate the adoption of agbiotech in the region.

Another facet is the negative perception and public distrust in SSA of foreign, private sector involvement in agbiotech, which poses a substantial challenge to the development and adoption of these technologies and products. The concerns expressed by stakeholders relate to the fact that the proprietary global seed market is controlled by only a few multinational seed companies, mostly in the North, whose business and innovation agendas are not necessarily in line with the food security concerns of SSA nations[4]. Stakeholders indicated that improved local participation of farmers and the public in development and provision of agbiotech approaches would likely be an effective way to improve transparency and accountability and build trust in agbiotech projects.

Note: Supplementary information is available on the Nature Biotechnology website.

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In the version of this supplementary file originally posted online, information regarding the positions of the participants and the organizations they belonged to was not complete. Complete information has been provided in this file as of 12 January 2012.

Supplementary Methods

The Ethical, Social, Cultural and Commercialization (ESC²) team, based at the McLaughlin-Rotman Centre for Global Health in Toronto, Canada, has been funded by the Bill & Melinda Gates Foundation to conduct annual social audits[i] on the Water Efficient Maize for Africa (WEMA) Project[ii] throughout its development and implementation phases. The purpose of these audits is to identify ESC² issues, from the perspectives of agro-biotechnology stakeholders in sub-Saharan Africa (SSA) that may impede the adoption of the WEMA drought-tolerant maize variety.

In preparation for the first social audit of the WEMA project, we conducted a qualitative study through a process of document analysis, discussions with WEMA program staff, and interviews with a wide variety of WEMA stakeholders[iii]. Accounts of ESC[2] issues of agro-biotechnology in sub-Saharan Africa were collected, which were found to be quite general in scope, rather than specific to the WEMA project. Understandings and perceptions of agro-biotechnology ESC[2] issues shared by stakeholders were based on a variety of experiences with agro-biotechnology in SSA beyond the WEMA project.

Participants

Participants represented five sub-Saharan, African countries: Kenya, Mozambique, South Africa, Tanzania, and Uganda. They were drawn from internal and external stakeholders of the WEMA project, including a variety of stakeholder groups: academics, agricultural extension services, agricultural commercialization enterprises, farmers, farmers associations and related stakeholders, legal consultants, maize processors/millers, media, national agricultural research institutes, non-governmental organizations, regional organization that work with small-scale farmers, national authorities, regulatory authorities, seed companies, and technical resources. They represented various positions and organizations, including: Directors in Crop Promotion, Extension Services, Technology Transfer, Technical Services, Information and Documentation, and Research and Coordination of the Tanzanian Ministry of Agriculture, Food Security, and Cooperatives, National Directorate of Agrarian Services in Mozambique, Tanzanian Agriculture Research Institute, Advocates Coalition for Development and Environment (ACODE), Tanzanian Commission for Science & Technology, National Institute of Agricultural Research in Mozambique, National Crops Resources Research Institute in Uganda, African Centre for Gene Technologies in South Africa, Kenyan Agricultural Research Institute (KARI), National

[i] "We define it [social audit] as a process whereby an audit team collects, analyses, and interprets descriptive, quantitative and qualitative information from stakeholders to produce an account of a project's ethical, social, cultural and commercialization performance and impact"[1].

[ii] The Water Efficient Maize for Africa Project (WEMA) is a public-private partnership (PPP), which seeks to introduce drought tolerant maize, royalty free, to small-scale farmers in Sub-Saharan Africa (SSA). WEMA partners include: African Agricultural Technology Foundation (AATF), International Maize and Wheat Improvement Centre (CIMMYT), Monsanto, and Bill & Melinda Gates Foundation (BMGF).

[iii] Stakeholders are those members of the community who have some stake, interest, and/ or concerns regarding the project in question. They may not be aware of the project but are likely a consumer or recipient of products or services resulting from the project. Just as key stakeholders may be affected by the project, they also play an important role in influencing the progress of the project[2].

Agricultural Research Organization in Uganda (NARO), National Agricultural Service Directorate in Mozambique, Africa Biotechnology in Kenya, CSIR Biosciences in South Africa, National Organic Agricultural Movement in Uganda, South African Biosafety, Seed Trade Association of Kenya (STAK), Costal Management in the Ministry of Environment in Mozambique, Maize Trust in South Africa, Kenya Seed Company Ltd., KK Agrovety Supplies Ltd. In Tanzania, PlantBio Trust in South Africa; Farmers in South Africa and Uganda; Leader of a Farmers' Association in Uganda; CEOs of an Economic Network in Kenya, South African Agricultural Business Chamber, Uganda Organic Certification Ltd., East Africa Farmers Federation (EAFF); Compliance Officer of the National Environmental Management Authority in Kenya; Researchers at Med Biotech Laboratories of NARO; Legal Officers in the Ministry of Science and Technology in Mozambique and Ministry of Agriculture, Food Security, and Cooperatives in Tanzania; Marketing Manager in Kenya; Administration Personnel at the Uganda National Council for Science and Technology (UNCST) and CSIR Biosciences Operations Group Biosafety in South Africa; Conflict and Reintegration Advisor for the US Agency for International Development in Uganda; and Consultant for FoodNCrop Bio in South Africa.

Attempts were made to interview supporters and opponents of agro-biotechnology as well as those who held neutral views.

Authors of this paper contacted between 100-115 key stakeholders, based on input from WEMA coordinators, past experience with the Grand Challenges in Global Health Initiative, literature searches, and sequential reference sampling. Stakeholders' views on agro-biotechnology were confirmed through individual biographies and word-of-mouth in the case of sequential sampling. Ninety-one stakeholders participated. Those who did not participate were unavailable due to lack of time or prior commitments.

Approximately 15-20 stakeholders were interviewed in each of four of the participating WEMA countries: Kenya, South Africa, Tanzania, and Uganda, while only 7 were interviewed in Mozambique. The gender distribution of the stakeholders was approximately 20% female and 80% male.

Data Collection

The interviews involved the administration of a questionnaire and face-to-face, semi-structured interviews, enabling diverse perspectives and detail of participants' responses to be collected. The questions asked of participants were in line with the ESC^2 analytical framework, which included seven domains: technical, regulatory, capacity building, deployment, project management and governance, charitable purpose, and communication.

The interviews took place in English and lasted approximately one hour. ESC² issues were not defined for the participants; instead, respondents were asked what they perceived to be ESC² issues that may affect the adoption of agro-biotechnology products in SSA. Specifically, questions such as "How well have the interests and concerns of the [stakeholder group] been considered in project planning and implementation?" and "What ethical, social, and/or cultural issues have been encountered in similar projects on GM crops?" were asked.

The flexibility of the interview guide allowed the interviewers to pursue novel issues that arose, and gave participants opportunities to share information on the basis of personal insights and/or

experience from other agro-biotechnology projects. This method resulted in the illumination of a broad set of ESC² issues that may arise in the adoption of agro-biotechnology in SSA.

Data Analysis

In our analysis of the interviews, we included any issue that the respondent characterized as ethical, social, cultural, or commercialization, as well as respondents' suggestions for addressing these issues. We identified several ESC² factors that may affect the uptake of agro-biotechnology products in SSA. Topical areas that were discussed in the interviews included: agro-biotechnology research in African research institutions, regulatory issues, deployment of agro-biotechnology crops, commercialization, capacity building, poverty alleviation for small-scale farmers through use of agro-biotechnology, as well as communication of agro-biotechnology and agro-biotechnology project developments.

Interviews, which were digitally recorded, were transcribed verbatim. A software tool, Atlas ti[3] was used for the analysis of the transcripts. Team members then coded the transcripts (i.e., systematic selection of a word or phrase to reflect the participants' text) and conducted analysis. Codes were organized into broad categories under which sub-categories were created, along with descriptive properties, including relevant quotations. This process of coding helped to organize and interpret approximately 1000 pages of interview text. These qualitative research methods were selected due to their strong potential to reveal complexity and capture the richness of collected data[4].

Upon completion of transcript analysis, analysts followed-up with study participants, who are cited in this paper, by verifying their quotations to ensure reliability of results. All named interviewees gave permission to be quoted. Anonymous participants chose not to be linked to their quotations but agreed to be listed among the study participants.

Limitations

We acknowledge that since our stakeholder sample involved only five countries in the SSA region, this could diminish the applicability of the results to SSA as a whole. However, key findings were recurrent across the five SSA countries, supporting their general relevance to the region. We also acknowledge that the interviews were partly in the context of an evaluation of the WEMA project, which may partially limit the generalizability of the findings. However, this allowed participants to use concrete examples, and most of the interviewees still referred broadly to issues around agro-biotechnology in the SSA region, as shown in the findings.

Ethics and Research Team

We obtained Research Ethics Board (REB) approval and consent from each participant prior to conducting these interviews. Throughout the process, participants were given the opportunity to withdraw voluntarily, at any time, and to pass on questions they were uncertain about or did not want to answer.

The interviews were conducted by five authors of this paper. In particular, Daar, Singer, and Thomas conducted some interviews, while Ezezika and Mabeya conducted the majority across the participating countries. Our colleague, Jerome Singh, also assisted with conducting interviews

in South Africa. An external transcriber was hired to complete transcription of all the audio files. Barber, Ezezika, Mabeya, and Wang completed the coding of the transcripts, after which codes were compared to analyses of both similar and varying themes. All authors are members of the WEMA ESC² team.

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