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Feeding East Africa: Are Genetically Modified Crops Part of the Solution?

Ida Arff Tarjem
Biotechnology

Abstract

Background. The African continent is faced with enormous challenges of poverty, hunger and food insecurity, which is exacerbated by climatic and environmental change, and a rapidly increasing population; and in the midst of it all is the smallholder and subsistence African farmer.

Some believe that genetically modified organisms (GMOs) and GM crops may offer part of the solution to some of these challenges. The GMO debate has gained considerable traction in the East African region, as recent regulatory amendments have opened up the door for commercialisation of GM crop plants. One GM crop that could possibly hit the East African market in a few years' time is banana resistant against the devastating bacterial disease, Banana Xanthomonas Wilt; a disease which is currently threatening the livelihoods of millions that rely on bananas and plantains (*Musa spp.*) for their staple food.

However, little is known about the potential impacts of GM crops on various components of the East African society and ultimately on the quality of life of the East African farmer.

Objective. The goal of this thesis was to investigate the potential role of GM crops in solving some of the current and future challenges in East Africa, including a real life example of GM bananas; how the technology may interact with several aspects of society, including human health, the environment, politics and socio-economics; and the level of awareness and perceptions that exists' on the topic among a range of stakeholders, including farmers.

For the purpose of this thesis, the countries that have implemented, or are in the process of developing, regulatory frameworks and policies governing biosafety and biotechnology were investigated, including the United Republic of Tanzania (from now on referred to as Tanzania), the Republic of Kenya (from now on referred to as Kenya), the Republic of Uganda (from now on referred to as Uganda) and the Federal Democratic Republic of Ethiopia (from now on referred to as Ethiopia).

Data source. *Social science study.* The thesis employed data from four perception studies conducted among: (i) agricultural researchers, extension workers, civil servants in the public/private sector related/not related to agriculture, civil servants employed in non-governmental organisations, policymakers and others from Kenya, Uganda, Tanzania and Ethiopia; (ii) Kenyan farmers; (iii) Ugandan farmers; and (iv) Tanzanian farmers.

Interviews. Additionally, interviews with Dr. Richard Okoth Oduor (Kenyatta University, Kenya), Dr. Faith Nguthi (International Service for the Acquisition of Agri-biotech Applications [ISAAA], *Afri*Center, Kenya), and Dr. Dawit Tesfaye Degefu (Ethiopian Institute of Agricultural Research) provided further insight into certain aspects of the debate.

Laboratory case study. Results from a practical laboratory project are also presented, whereby the banana cultivars 'Cavendish Williams' and 'Sukali Ndiizi' were transformed using *Agrobacterium*-mediated transformation for the expression of the reporter genes green fluorescent protein (*gfp*) and β-glucuronidase (*gusA*).

Analysis. The thesis analysed the level of awareness, attitudes, perceptions and acceptance of GM crops among East African stakeholders and farmers, and the potential demographic and geographical effects on such factors, using descriptive statistics and specifically designed Monte Carlo simulation models. Additionally, the results obtained through the laboratory work include GUS and GFP assays and PCR analysis to verify successful gene insertion and expression.

Results. *Social science study.* The majority of stakeholders with a professional involvement in the debate expressed positive attitudes and perceptions towards GM crops, and further perceived recent governmental and public attitude changes as having been in favour of the technology. Still, several participants expressed concerns about potential environmental, trade related and socio-economic effects. Stakeholders further identified a range of obstacles and measures needed for the successful widespread adoption of GM crops. The results from the simulation models showed that there were significant differences in stakeholder responses on the basis of the respondents' general attitude towards the technology, occupational group, and at times educational level and nationality. Additionally, demographics such as sex, age, family background, upbringing, knowledge of agriculture and farming life, and cultural leaning appeared to have an effect for certain of the issues addressed in the questionnaire.

In most cases, there were significant differences in the level of awareness, favourable impressions, perceptions and acceptance of GM crops among farmers within and across study countries. In Kenya, the majority of farmers were aware of GM crops, while awareness was considerably lower among Tanzanian and Ugandan farmers. Kenyan and Tanzanian farmers exhibited high levels of favourable impressions of the technology, while only a slight majority of Ugandan farmers had a favourable impression. Kenyan and Ugandan farmers had high levels of concerns associated with the GM crops, including health and environmental effects, low profitability and consumer reluctance. Still, a majority of farmers across all study countries would grow GM crops if given the opportunity, believed that GM crops could help improve the quality of life of farmers, and supported the commercialisation of the technology. The study further lends relatively little support for any demographic effects on farmer awareness and perceptions, though a few significant correlations were found for educational level, sex, marital status and cultural leaning.

Laboratory case study. 'Sukali Ndiizi' was the only cultivar for which embryos successfully regenerated into whole transgenic plantlets. The PCR analysis conducted for lines of 'Sukali Ndiizi' transformed with *gusA* yielded amplicons of the expected size, thus provided strong evidence of complete T-DNA insertion. Contrary, the PCR analysis performed for lines of 'Sukali Ndiizi' transformed with *gfp* did not yield any amplicons, which indicates that the T-DNA has not been successfully integrated.

Conclusions. Overall, the majority of farmers and stakeholders with a professional background expressed relatively high levels of positive perceptions and acceptance of GM crops. The simulation model demonstrated that general attitude towards GMOs, occupational group, educational level and at times nationality had the most prominent effects on the perceptions of stakeholders with a professional involvement in agricultural biotechnology. In the case of farmers, the model demonstrated relatively few demographic effects, with the exception of educational level, sex, marital status and cultural leaning. However, there were significant differences in the level of awareness, attitudes and perceptions of GM crops on the basis of geographical location (i.e. within

and between study countries). Such differences may be explained by factors such the level of public advocacy and impact of the GMO debate, prior knowledge of the underlying technology, risk/benefit perception, level of trust in various institutions and governments, culture and tradition, and differences in the socio-economic and socio-political environment.

The findings from the present study suggests that GM crops could represent a complementary solution alongside conventional practices and agro-ecological farming, as a way of meeting some of the challenges faced by the East African region. One such potential crop may be bananas resistant against Banana Xanthomonas Wilt. Still, the successful widespread adoption of GM crops may require a range of measures, including – but not limited to – awareness and educational efforts, and improved regulatory, scientific, technical, human and infrastructural capacity.

Note: Certain chapters leading up to the main findings from the social science study (Chapter 24) contain results from the perception studies where appropriate. Thus, it is advisable to get familiarised with the "Materials and methods" (section 24.2) before embarking on the thesis. Chapter 6 is dedicated in its entirety to the practical laboratory project.

Foreword and Acknowledgement

To whomever it may concern,

It would take less than twenty-four hours from the time I arrived in Nairobi, Kenya, one August evening in 2016, till I got dragged into the debate on genetically modified organisms (GMOs) and GM crops. The morning after my arrival, the driver who was taking me to the International Institute of Tropical Agriculture (IITA) – where I would spend the next four months learning the methods used to genetically transform bananas – had brought up the topic completely unprovoked; he was worried about the dwindling biological diversity he observed in many of the crops he held so dear, and was concerned that GM crops would make matters worse. He further feared potential health effects of eating products thereof, and compared GMOs to cigarettes; "How can I trust a government that once allowed for commercialisation of cigarettes? What if GMOs are just as bad?". In his opinion, there were a number of alternative courses of action that should be taken before "going as far as GMOs", including the use of conventional methods and improving the many infrastructural limitations that characterised the country and farming life.

As apparent from the discussion I had with the Kenyan driver, the debate on GMOs is more relevant than ever; not just in Kenya, but large parts of the East African region. Kenya recently allowed for environmental release of GM maize and cotton; Uganda has long been an attractive destination for foreign companies, institutions and donor agencies that wish to carry out research and development, and the passage of the National Biotechnology and Biosafety Bill into law is soon to be tabled in the Parliament; Ethiopia and Tanzania recently made amendments to their regulatory systems which has paved the way for the first confined field trials and perhaps even commercialisation.

However, the dynamics between novel technologies and societal factors is complex, yet intriguing; perhaps even more so in a region faced with enormous challenges of poverty, socio-economic and socio-political injustice, food insecurity and environmental change.

Thus, when my supervisor Professor Trine Hvoslef-Eide initially proposed the opportunity to experience the debate on GM crops first-hand in Kenya, there was no doubt in my mind that this was what I wanted – and needed – to do. As cliché as it might sound, the experience has changed my perspectives completely, both academically and personally. So to my supervisor Trine – thank you for believing enough in me to allow me to go on this journey, as well as providing support and guidance when I needed it the most.

Also, huge thanks goes to Dr. Leena Tripahti and Dr. Jaindra Tripathi – my supervisors at IITA – who not only taught me more in a matter of months than I had previously learnt over the course of several years, but also showed great compassion and hospitality. Furthermore, my experience would never have been the same without the most incredible team of co-workers, including – but not limited to – June, Evelyn, Rose Harriet, Sarah, Jackie, Easter, Tope, Pauline, Ibsa, Jiregna, Jonathan, Bernard, Susan, Peninah, Ana Luisa and last – but not least – Mark. Never have I experienced a group of people more warm-hearted, fun, hard-working and supportive. Thank you all for taking me under your wings from day one, and making it feel like home – so far from home.

I also want to thank Dr. Shiferaw Feleke and Dr. Victor Manyong at IITA, Tanzania, whose help and guidance has been pivotal for the execution and understanding of the work at hand, as well as for providing funding for the work conducted in Tanzania. I would also like to express my gratitude to Mr. Julius Nyalusi, and Mr. Patrick Muriuki and the rest of ICOSEED, who made it possible for the voices of Kenyan, Ugandan and Tanzanian farmers to be heard. Additionally, Professor Arne Huseby at the University of Oslo deserves a huge amount of credit for his help on the statistical analyses. Furthermore, many thanks to all who participated in interviews and the various perception surveys, particularly to the farmers who displayed an enormous degree of patience, kindness, hospitality and curiosity. This thesis is for you.

Finally, I would like to thank my friends and family in Norway who supported me throughout this journey, especially when I needed it the most. I could not have done this without you.

Asante sana!

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List of Acronyms and Abbreviations

AATF: African Agriculture Technology Foundation

ABI: African Biosciences Initiative

ABNE: African Biosafety Network of Expertise

ABFS: African Biotechnology Stakeholder Forum

ACTESA: Alliance for Commodity Trade in East and Southern Africa

AEZ: Agro-Ecological Zones

AIA: Advance Informed Agreement (Ethiopia)

ANBAA: Association of National Biosafety Agencies in Africa

ARIPO: African Regional Industrial Property Organization

ASARECA: Association for Strengthening Agricultural Research in East & Central Africa

AU: African Union (previously known as Organisation of African Union, OAU).

B4FA: Biosciences for Farming in Africa

BecA-ILRI: Biosciences Eastern and Central Africa – International Livestock Research Institute

BIO-EARN: The Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development

BXW: Banana Xanthomonas Wilt

CBD: Convention on Biological Diversity

CCA: Chinese Academy of Agriculture

CGIAR: Consultative Group on International Agricultural Research

CIMMYT: International Maize and Wheat Improvement Centre

CIP: International Potato Center

COMESA: Common Market for Eastern and Southern Africa

CPB: Cartagena Protocol on Biosafety

EAC: East African Community

EALA: East African Legislative Assembly

EAPGREN: Eastern African Plant Genetic Resources Network

EIA: Environmental Impact Assessment

EMA: Environmental Management Act (Tanzania)

EMBRAPA: Brazilian Agricultural Research Corporation (Ministry of Agriculture, Livestock, and Food Supply)

EPA: Environmental Protection Authority (Ethiopia) (note that EPA may refer to the United States Environmental Protection Agency in a few cases)

FAO: The Food and Agriculture Organization

GAP: Good Agricultural Practices

GM/O: Genetically Modified / Organism

HT: Herbicide Tolerant IARC: International Agricultural Research Centre

icipe: International Centre of Insect Physiology and Ecology

IFPRI: International Food Policy Research Institute

IITA: International Institute of Tropical Agriculture

IPM: Integrated Pest Management

IPRs: Intellectual Property Rights

IR: Insecticide Resistant

IRMA: Insect Resistant Maize for Africa

ISAAA: The International Service for the Acquisition of Agri-biotech Applications

ITPGRFA: International Treaty on Plant Genetic Resources for Food and Agriculture

IYA: IITA Youth Agripreneurs

KALRO: Kenya Agriculture and Livestock Research Organization (formerly known as Kenya Agriculture Research Institute, KARI).

Kephis: Kenya Plant Health Inspectorate Service

KOAN: Kenya Organic Agriculture Network

LAC: African and Latin American and Caribbean

LMO: Living Modified Organism

NARO: National Agriculture Research Organisation (Uganda)

NBA: National Biosafety Authority (Kenya)

NBC: National Biosafety Committee (Kenya)

NBF: National Biosafety Framework

NBFP: National Biosafety Focal Point

NCST: National Council for Science and Technology (Kenya)

NARL: National Agriculture Research Laboratories (Uganda)

Nema: National Environmental Management Authority (Kenya)

NEPAD: New Partnership for Africa's Development (the technical body of the African Union)

NERICA: New Rice for Africa

NGO: Non-Governmental Organisation

NPT: National Performance Trial

OFAB: Open Forum on Agricultural Biotechnology

PBS: Program for Biosafety Systems

PPP: Public-Private Partnership

R&D: Research and Development

RABESA: Regional Approach to Biotechnology and Biosafety Policy in Eastern & Southern Africa

SACBB: Southern Africa Committee on Biotechnology and Biosafety

SADC: Southern Africa Development Community

SCIFODE: Science Foundation for Livelihoods and Development

Sida: Swedish International Development Cooperation Agency

TRIPS Agreement: Agreement on Trade-Related Aspects of Intellectual Property Rights

UBBC: Uganda Biotechnology and Biosafety Consortium

UBIC: Uganda Biosciences Information Centre

UNCST: Uganda National Council for Science and Technology

UNEP-GEF: United Nations Environment Programme-Global Environment Facility

USDA: United States Department of Agriculture

VIRCA: Virus Resistant Cassava for Africa

WEMA: Water Efficient Maize for Africa

WTO: World Trade Organization

Part A. The Problem

Chapter I. Introduction

1.1. Current situation and future outlook for Africa

Agriculture represents the major mean of income and livelihood for approximately 70% of the African population, while the agricultural sector accounts for an average of 1/3 of the GDP and ½ of the export earnings of most African countries, thus making up the backbone of the economy (OECD, 2009; ISAAA, s.a.). Still, the continent has the highest prevalence of hunger in the world and one-in-four are undernourished (FAO, IFAD & WFP, 2015).

Millions of African smallholder farmers suffer greatly from the highly variable climatic and environmental conditions that characterise large parts of the continent. Drought is a major contributor to crop failure, famine and poverty, especially as many farmers rely solely on rainfall to water their crops (AATF, 2012a). Additionally, African soils are characterised by low fertility, an estimated 80% of land areas are endangered by degradation, and two million hectares of forest is lost annually, leading to increased desertification (UNDP, 2012; ISAAA, s.a.). Furthermore, smallholder farmers have little or no resources to effectively manage pests and pathogens, which further exacerbate the negative effects experienced during drought, as pests will attack whatever crop is left, as well as limiting the plant's ability to utilise water and nutrients (AATF, 2012a).

Faced with global warming and climate change, conditions are predicted to worsen – the 2011 East African drought was the worst in 60 years, whereby 4 million people required food aid in Kenya alone (Rural Poverty Portal, s.a.; Wooldridge, 2011). Ethiopia is currently suffering from failure of harvest and death of livestock due to drought, which has resulted in a tripling of humanitarian needs in little over one year (WFP, 2016). Recently, the United Nations World Food Programme (WFP) reported that 16 million people in Eastern and Southern Africa are threatened by famine from the most potent El Niño in 75 years, and that the number could climb to 50 million (WFP, 2016).

Concurrently, the population of Africa continues to grow at an alarming speed – from the current ~1 billion to an estimated 2.8 billion by the end of 2060 (Canning *et al.,* 2015). The question thus remains: How is Africa going to face her unique current and future challenges of famine, hunger and food insecurity (Box 1.1)?

Box 1.1. Food security. The State of Food Insecurity 2001 defined food security as: "…a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2001). The concept often refers to availability of food (quantity and diversity); access to food (physically and financially); utilisation of food (i.e. capacity and resources necessary to use and store food, which is dependent on e.g. health status); and stability of food availability in the short and long-term (Fransen *et al*., 2005). Food insecurity is commonly counteracted by increasing food production and/or by alleviating poverty which allows people to purchase food (Fransen *et al*., 2005).

1.2. Could genetically modified (GM) crops be part of the solution?

What are genetically modified crops and foods? The WHO defines genetically modified (GM) foods as "foods derived from organisms whose genetic material (DNA) has been modified in a way that does not occur naturally, e.g. through introduction of a gene from a different organism" (WHO, s.a.). In other words, a GM plant (also referred to as a biotech or transgenic plant) exhibits a novel combination of genetic material obtained via genetic engineering, with the aim of conferring a certain trait(s) such as pest and disease resistance, herbicide resistance, resilience to abiotic factors (e.g. drought), improved nutritional value, and so forth (FDA, 2015). As opposed to conventional/traditional breeding – which is also a type of genetic modification – biotechnological methods circumvents barriers of sexual incompatibility, are considered more precise and targeted, and avoid the laborious steps of backcrossing (which can result in decades of effort for the introduction of a new conventionally-bred variety) (Manshard, 2004; Slater *et al.*, 2008; FDA, 2015).

How widespread are GM crops? Since the first GM product was introduced to the US market in 1994 (Bruening & Lyons, 2000), the global adoption of GM crops has increased by approximately a factor of 100, from 1.7 million hectares in 1996 to over 185 million hectares in 2016 (Fig. 1.1) (James, 2015; ISAAA, 2016a). This makes biotech crops the fastest adopted agricultural technology in recent times (James, 2015). Today's GM market is dominated by four crops (maize, cotton, canola and soya) harbouring two traits (insecticide resistance [IR] and herbicide tolerance [HT]) (James, 2014; ISAAA, 2016a; Elliott & Madan, 2016).

The year 2016 marked the fifth consecutive year in which developing countries planted more GM crops than developed ones (ISAAA, 2016a). In fact, of the 18 million farmers who chose to cultivate biotech crops, 90% were small-scale and resource-poor (ISAAA, 2016a). However, only three African countries allow for commercialised events (Box 1.2), namely Burkina Faso, South Africa and Sudan (James, 2015), which constitute less than 2% of the total global area (Elliott & Madan, 2016). Prior to 2012, insect resistant Bt maize was cultivated in Egypt (see Chapter 3, Box 3.1 for an explanation of the Bt trait), but plantings were discontinued in 2012 due to proposed safety claims (ISAAA, 2016a).

Box 1.2. Transgenic event. A transgenic event is defined as "incorporation of a particular package of genetic material in a defined place in the plant genome" (European Commission, 2017). From a single transformed plant (cell), several plants can be produced which all are considered the same event. Examples include MON180, i.e. insect resistant Bt maize which is cultivated worldwide.

Burkina Faso, South Africa and Sudan all grow insect resistant Bt cotton, while South Africa also cultivates GM maize and soybeans (James, 2015). In 2016, South Africa experienced a 16% increase in the hectares devoted to biotech crops from the year before (with a resulting >1 million hectares), while there was a slight increase in hectares in Sudan from year 2015, totalling at 120 600 (ISAAA, 2016a). However, due to technical issues related to variability in fibre length, the government in Burkina Faso decided to put a temporary stop to Bt cotton plantings in 2016 (ISAAA, 2016a). According to ISAAA (2016a), the government has stated that this decision was not based on concerns associated with the technology itself, and that the plan is to reinstate planting of Bt cotton as soon as possible.

Additionally, ten African countries (Nigeria, Ethiopia, Ghana, Cameroon, Kenya, Uganda, Tanzania, Malawi, Mozambique, Swaziland) are currently carrying out confined field trials of GM crops with traits for nutritional enhancement, pest and disease resistance, salt tolerance, increased nitrogen-use efficiency, and resilience to drought, heat and waterlogging (Bailey *et al*., 2014; ISAAA, 2014; ISAAA, 2016a).

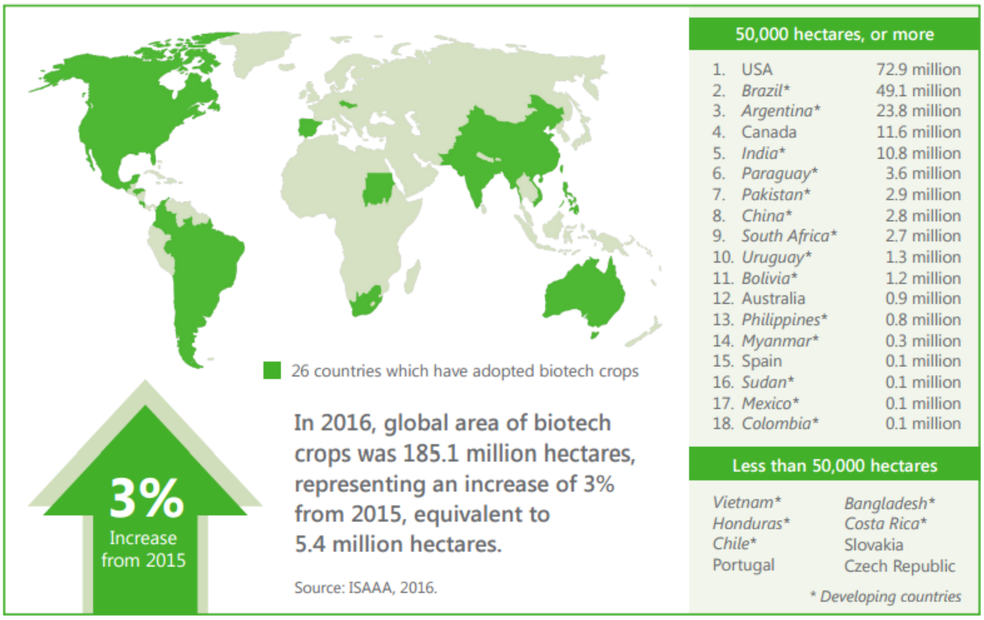


Figure 1.1. Million hectares of cultivated biotech crops globally, from 1996 to 2016. Figure from: ISAAA, 2016a.

What potential do biotech crops hold? Global meta and impact studies indicate that biotechnology can be a powerful tool to combat food insecurity, alleviate poverty, improve the quality of life of farmers, and support sustainable agriculture (The Royal Society, 2000; Klümper & Qaim, 2014; ISAAA, 2016a; Brookes & Barfoot, 2017). For instance, Klümper & Qaim (2014) found that the adoption of GM crops have reduced the use of chemical pesticides by 37%, increased crop yields by 22%, and increased farmers profit by 68%. Such findings are supported by impact studies from individual countries; in India, the introduction of Bt cotton has reduced the use of pesticides by at least 50% and increased yields by a minimum of 24% (Kathage & Qaim, 2012). In Burkina Faso, planting of Bt cotton has led to an average increase in yield by 18.2%, a reduction in pesticide-use by 2/3, and an increase in income level by $61.88 per hectares when compared to conventional cotton (Vitale *et al*., 2010, 2016).

1.3. Genetically modified organisms (GMOs) remain a controversial topic

Despite the many proposed benefits, the topic of GM crops remains controversial, even some twenty years after the first variety was commercialised. Despite being the most regulated technology in agricultural history (Chambers *et al*., 2014), and several reports support its safe usage (e.g. The Royal Society, 2002; Persley, 2003; WHO, 2005; Domingo & Bordonaba, 2011; Nicolia *et al*., 2013; European Commission, 2010), some still question whether the technology will do more harm than good to humans, animals and the environment.

Indeed, society is a complex organism, and a range of factors – including social, cultural, religious, ethical, economic and political – may complicate the transfer of science and technology from one context to another (Tripp, 1997; Altieri & Rosset, 1999; Keeley & Scoones, 2003). Furthermore, just as the proposed benefits of biotech crops can be significant and even greater for developing countries, so can the potential demerits, especially in countries that lack human, regulatory and technical capacity to efficiently assess and manage risks (Meijer & Stewart, 2004).

Chapter 2. The East African Agricultural Sector

2.1. The importance of the agricultural sector in Africa and East Africa

The economies of Kenya, Uganda, Tanzania and Ethiopia are all agriculture-based (Salami *et al*., 2010), though the contribution of the agricultural sector to the gross domestic product (GDP) varies (i.e. 37%, 36%, 31% and 24% of the GDP in Ethiopia, Kenya, Tanzania and Uganda, respectively) (World Bank, 2017). The sector is the biggest creator of job opportunities, especially for the rural poor, and the majority of the labour force (~75%) originates from agriculture (Salami *et al*., 2010). For instance, in Ethiopia, around 12.7 million smallholder farmers produce 90-95% of the agricultural output (while still representing the largest group of poor people in the country) (IFAD, 2016).

Government investment in the agricultural sector has positive impacts on alleviating poverty (4.25 times more so than for similar investment in other sectors) (Pingali, 2010), on trade and investments, and in promoting industrialisation and economic diversification (Blein *et al*., 2013; Salami *et al*., 2010; Townsend, 2015). For instance, between 2004 and 2014, Rwanda increased its investment in agriculture from 3.5% to 7.2%, which led to a doubling of the country's crop production and a reduction in poverty by almost a third (AGRA, 2014).

In recognition of the importance of the agricultural sector, the African Union's (AU) Maputo Declaration of 2003 and the Comprehensive Africa Agriculture Development Programme (CAADP) established a 10% threshold for governmental expenditure to agriculture in order to achieve a 6% sectoral growth (NEPAD, 2003; NEPAD, s.a.-a). Encouragingly, East Africa was the only region to achieve a 6% growth rate, though Ethiopia was the only country to reach the 10% goal (Anisimova, 2016). In fact, the Ethiopian government allocated an average of 22.5% to the agricultural sector between 2006 and 2012 (Salami *et al*., 2010; Okeno *et al*., 2013; Blein *et al.*, 2013; FAO, 2014a, 2014b; FAO, 2015). However, it should be noted that the *composition* of the public expenditure to agriculture is often unequally balanced (FAO, 2014a, 2014b, 2015). For instance, only 30% of the Ethiopian expenditure was allocated to agriculture-supportive spending, e.g. rural education, health and infrastructure (FAO, 2014a). In Tanzania, an estimated 0.36% of the agricultural GDP was allocated to agricultural research over a ten year period, which is below the recommended 1% (as cited by Virgin *et al*., 2007).

Due to the failure of most AU Member States to meet the 10% target, the AU Malabo Declaration was established in 2014 in hopes of promoting the goal further (African Union Commission, 2014).

2.2. Characteristics of East African farming systems

Most of the available land in East Africa is fragmented into smaller plots and production systems (Salami *et al*., 2010).For instance, the average farm size in Kenya was 0.86 hectares (ha) in 2005, while it was 1.82 ha in Ethiopia in 2012 (FAO, s.a.-a). 75-80% of farms are family-driven and subsistence, whereby traditional practices are employed and with little use of machinery (Salami *et al*. 2010; Blein *et al*., 2013). Furthermore, most farms are rainfed as opposed to irrigated, though the percentage varies from country to country (Wani *et al*., 2009; Njenga *et al*., 2013).

The major crops include cereals (e.g. maize, wheat, sorghum, rice and millet), pulses (e.g. beans and chickpeas), root and tuber crops (e.g. cassava, potato, sweet potato and yams), banana, tea, coffee, cotton and tobacco (Salami *et al*., 2010). Most farmers carry out intercropping whereby a variety of crops are cultivated together in the same fields (Garrity *et al*., 2012; observations during farmer surveys).

2.3. Intrinsic and extrinsic factors influencing agricultural productivity

Uganda is considered the country with the best agricultural conditions due to its fertile soils and favourable climate, and 34.4% of the total land area is considered arable (as of 2013) (Pannhausen & Untied, 2010; World Bank, s.a.-a). Tanzania exhibits many high production zones, especially the mountainous areas, while the central part of the country is semi-arid (Pannhausen & Untied, 2010). In 2013, 15.2% of the total land area was arable (World Bank, s.a.-a). In Kenya, 3/4 of the land is semi-arid and 10.2% is considered arable (as of 2013) (Pannhausen & Untied, 2010; World Bank, s.a.-a.). Ethiopia is characterised by extremely variable agro-climatic and topographic conditions which affect the productivity of the soil (Mengistu, 2006). The total percentage of arable land in Ethiopia is 15.1%, whereby only 25% is currently cultivated (World Bank, s.a.-a.).

Small-scale farm plots are often characterised as being unproductive and uneconomic due to lack of access to markets and technology (further elaborated on in Chapter 21) (Salami *et al*., 2010). For instance, the adoption of hybrid seeds, fertilisers, pesticides, mechanisation and machinery is relatively low, thus there is great potential for improving productivity through adoption of such technologies (Njenga *et al*., 2013). Furthermore, short periods of fallow, overcropping, soil erosion, land degradation and drought further contribute to low soil fertility and production (Azadi *et al*., 2011).

2.4. Gender-based division of agricultural labour

There is a rigid division of labour based on gender in many East African farming communities. For instance, women typically make up ~70% of the agricultural work force, thus providing the backbone of production (Kameri-Mbote, 2012). Some communities distinguish between male and female crops; cash and export crops are often considered male, while female crops often constitutes lower valued subsistence crops (Doss, 1999). Such a division reflects the limited access to land, inputs, markets, credit and information by women (Doss, 1999; Uganda Bureau of Statistics, 2012).

2.5. Social status of the East African farmer and youth attitudes towards farming

The East African farmer is often recognised as having low social status and with little influence on decision-making concerning, amongst other, management and use of plant genetic resources (Naluwairo, 2006). Furthermore, the average East African farmer faces challenges associated with limited social and financial capital, inadequate access to credit, uncertainties concerning land tenure, lack of mechanisms for transferring rights and consolidate plots, and unequal access to land and subsidies (e.g. for agricultural inputs and technology) (Naluwairo, 2006; Paarlberg, 2010a; Salami *et al*., 2010;Sánchez, 2010; Azadi *et al*., 2011).

Youth attitudes towards farming have become an important consideration as an increasing number of young people migrate to urban centres to look for more well-paid jobs within the service and industrial sectors, which results in the agricultural sector becoming increasingly dominated by ageing farmers (Afande *et al*., 2012; Karembu, 2017). Consequently, there is a need to make farming more attractive to the younger generations, such as through adoption of new technology which allows for labour-savings and increased income (Karembu, 2017). For instance, the International Institute of Tropical Agriculture (IITA) in Nigeria initiated the Youth Agripreneur (IYA) program in 2012, which offers training and consultancy within leadership, entrepreneurship, management and adoption of the best available technologies to rural and urban youth that wish to form their own enterprises based on the agricultural value chain (Adenmosun, IITA Nigeria, pers. comm.). Additionally, IITA has established partnerships with transnational organisations and other stakeholders which provide funding needed to create job opportunities for young people in agribusinesses. The IYA initiative has later on been adopted in countries such as Kenya, Tanzania and Uganda (Adenmosun, pers. comm.).

2.6. Findings from the Stakeholder and farmer perception surveys

Stakeholders considered "incidence of crop pest and diseases", "low crop productivity and yield" and "climate change (drought and floods)" as the biggest challenges facing the agricultural sector in East Africa (Table 2.1). "Misguided agricultural policies" and "lack of secure land tenure and property rights" was considered less important (Table 2.1).

Table 2.1. The degree of challenge associated with various agricultural constraints as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not challenging	Somewhat challenging	Challenging	Very challenging	No answer
Incidence of crop pest and diseases	0.0 [0]	6.4 [5]	17.9 [14]	74.4 [58]	1.3 [1]
Low crop productivity and yield	1.3 [1]	5.1 [4]	21.8 [17]	71.8 [56]	-
Climate change (drought, floods)	1.3 [1]	2.6 [2]	25.6 [20]	70.5 [55]	-
Lack of irrigation systems	3.8 [3]	10.3 [8]	30.8 [24]	52.6 [41]	2.6 [2]
Youth attitude towards farming	2.6 [2]	11.5 [9]	32.1 [25]	50.0 [39]	3.8 [3]
Poor infrastructure for market access	2.6 [2]	9.0 [7]	41.0 [32]	47.4 [37]	-
Lack of improved agricultural technologies	2.6 [2]	9.0 [7]	39.7 [31]	47.4 [37]	1.3 [1]
Inadequate extension services	1.3 [1]	14.1 [11]	38.5 [30]	46.2 [36]	-
Land degradation	2.6 [2]	14.1 [11]	33.3 [26]	43.6 [34]	6.4 [5]
Inadequate credit services	2.6 [2]	20.5 [16]	33.3 [26]	42.3 [33]	1.3 [1]
Lack of secure land tenure and property rights	7.7 [6]	24.4 [19]	29.5 [23]	38.2 [29]	1.3 [1]
Low adoption rate of improved technologies	3.8 [3]	17.9 [14]	42.3 [33]	34.6 [27]	1.3 [1]
Misguided agricultural policies	12.8 [10]	29.5 [23]	26.9 [21]	29.5 [23]	1.3 [1]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

Consistent with the findings from the stakeholder survey, Kenyan, Ugandan and Tanzanian farmers also considered "climate change", "incidence of crop pest and diseases" and "low crop productivity and yield" among the most challenging constraints, as well as "lack of irrigation systems" and "post-harvest losses" (Table 2.2). Of lesser importance was "lack of secure land tenure and property rights", "spending too much time in the field" and "poor infrastructure for market access (roads, communication)" (Table 2.2).

Table 2.2. The degree of challenge associated with various agricultural constraints, as perceived by Kenyan, Ugandan and Tanzanian farmers; in % and [number] of total participants [2074].

	Not challenging at all	Somewhat challenging	Challenging	Very challenging	No answer
Climate change (drought, floods)	1.7 [37]	12.2 [254]	16.6 [346]	66.4 [1379]	2.7 [58]
Incidence of crop pest and diseases	1.5 [33]	7.0 [146]	28.9 [600]	61.4 [1274]	1.0 [21]
Lack of irrigation systems	3.6 [75]	4.9 [102]	29.7 [617]	60.8 [1263]	0.8 [17]
Low crop productivity and yield	1.7 [36]	6.4 [134]	31.9 [662]	59.4 [1232]	0.4 [10]
Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	3.8 [80]	15.5 [323]	23.3 [485]	56.6 [1175]	0.5 [11]
Poor quality of produce	2.6 [54]	18.6 [387]	30.1 [626]	48.0 [996]	0.5 [11]
Inadequate credit services (unable to afford inputs)	6.3 [131]	17.6 [367]	27.1 [564]	47.8 [992]	9.6 [20]
Land degradation	5.4 [114]	13.8 [288]	31.2 [649]	47.5 [986]	1.7 [37]
Inadequate extension services	14.8 [308]	14.7 [305]	20.4 [424]	47.1 [978]	2.8 [59]
Debt (e.g. from having to buy inputs at high price and sell output at low prices)	1.6 [35]	18.3 [381]	32.6 [677]	46.8 [971]	0.4 [10]
Post-harvest losses	1.8 [38]	14.6 [303]	38.1 [791]	43.2 [897]	2.1 [45]
Poor infrastructure for market access (roads, communication)	5.3 [111]	21.5 [446]	30.4 [631]	41.4 [859]	1.3 [27]
Spending too much time in the field (i.e. insufficient time for other activities)	5.5 [115]	26.4 [549]	33.1 [688]	33.4 [694]	1.3 [28]
Lack of secure land tenure and property rights	34.4 [714]	20.7 [430]	18.9 [394]	23.6 [490]	2.2 [46]

However, for most of the issues addressed, there were significant differences between geographical locations (between and within countries) and the perceived degree of challenge (Appendices 1, Appendix D.6-D.8). For instance, Tanzanian farmers generally found agricultural constraints overall less limiting than Kenyan and Ugandan farmers (Appendices 1, Appendix D.1). Differences within and among countries is likely to reflect variable agro-ecological, environmental, climatic, socio-economic and socio-political conditions.

PART B. Potential Solutions in Biotechnology

Chapter 3. Potential Solutions in Biotechnology for Current and Future Challenges in East Africa

3.1. Introduction

Biotech crops have many proposed benefits that could help East African countries face some of their unique challenges, including adaptation to climatic and environmental change, low productivity, malnutrition, pest and diseases, and post-harvest-losses. Table 3.1 depicts transgenic traits that were considered desirable by all farmers surveyed. Thus, such characteristics should be targets of agri-biotech projects, of which many are already in the East African biotech pipeline (Chapter 4, Table 4.1).

Table 3.1. Percentage (%) and [number] of surveyed Kenyan, Ugandan and Tanzanian farmers that perceived various transgenic crop traits as desirable.

	Kenyan farmers [1127]	Ugandan farmers [142]	Tanzanian farmers [805]	Total/average [2074]
Pest and disease tolerance	87.7 [989]	100 [142]	97.8 [788]	~93 [1919]
Higher nutritional value and quality	87.7 [989]	100 [142]	97.6 [786]	~92 [1917]
Increase yield	86.9 [980]	100 [142]	98.0 [789]	~92 [1911]
Enhanced storage capacity	87.7 [989]	100 [142]	95.1 [766]	~91 [1897]
Drought-tolerance	84.3 [951]	100 [142]	97.8 [788]	~91 [1881]
Improved nitrogen-use efficiency	85.3 [962]	100 [142]	96.2 [775]	~91 [1879]

The subsequent sections will address both first and second-generation GM crops, whereby the former often constitutes varieties for higher productivity and where most of the benefits go towards the farmer, while the latter comprise crops for enhanced food quality with the added benefit to the consumer (Buiatti *et al*., 2013). Third-generation biotech crops, which are plants intended for the production of pharmaceuticals (e.g. the production of antibodies against Ebola in *Nicotiana benthamiana*; Fulton *et al*., 2015) and other nutraceutical products (Sala *et al*., 2003), could also hold great promise for many African communities in which incidences of HIV/AIDS and other neglected tropical diseases are high, and whereby the administration of medicine seldom reach those who need it the most (Sithole-Niang, 2007). However, third-generation GM crops will not be investigated in further detail as they are either currently not in the East African biotech pipeline or under regulatory evaluation (for those interested, please refer to e.g. Sala *et al*., 2003; Goldstein & Thomas, 2004; Kumar *et al*., 2013).

Finally, conventional measures that can work alone or along-side the employment of biotech crops will also be presented in various sections.

3.2. Environmental benefits

3.2.1. Climate change and its impact on East Africa agriculture

Projections of climate and environmental change for Africa. The African continent is considered particularly vulnerable to global warming and environmental change, especially the arid/semi-arid and grassland sub-regions of Eastern and Southern Africa (IARSAF, 2007). Climate change models predict a more rapid temperature increase in Africa than anywhere else in the world – it is expected to exceed 2˚C by 2050 and 4˚C by the end of the century (IPCC, 2014). Weather and precipitation patterns are likely to change, including higher prevalence and severity of extreme weather such as drought and floods, all of which will exacerbate the wide rainfall deficit and challenges of water resource management (Barron *et al*., 2003; Mupangwa *et al*., 2006; IARSAF, 2007; Conway, 2009; Njenga *et al*., 2013; Rural Poverty Portal, s.a.). Extreme weather, such as long periods of drought, also has other ecological consequences, including elimination of grass cover and other flora, reduced level of groundwater and an increase in shifting sands, erosion and evaporation (IARSAF, 2007).

Climate change and agriculture. As apparent in Chapter 2 (Table 2.1 and 2.2), climate change was considered among the most important constraint to East African farming systems by both stakeholders and farmers. Climate is the main determinant for agricultural productivity, and global warming and environmental change are predicted to cause an overall decline in agricultural yield and production (Fig. 3.1) (Kurukulasuriya & Mendelsohn, 2008; Khang *et al*., 2009; Sultan, 2012; Rural Poverty Portal, s.a.). Increased heat and water stress can lead to a reduction in the growth season and the reproductive phase, fewer and smaller organs, alterations in the carbon-assimilation process, and higher incidence and severity of pest and diseases in plants (Stone, 2001; Prasad *et al*., 2008; Lobell & Gourdji, 2012; Bita and Gerats, 2013; IPCC, 2014). Furthermore, water and heat stress are likely to reduce areas suitable for cultivation, especially along arid and semiarid regions (Conway, 2009; CIAT, 2011a, 2011b). Increased intensity of rainfall is further thought to accelerate the rate of soil erosion, which poses additional threats to agricultural productivity (Nearing *et al*., 2004).

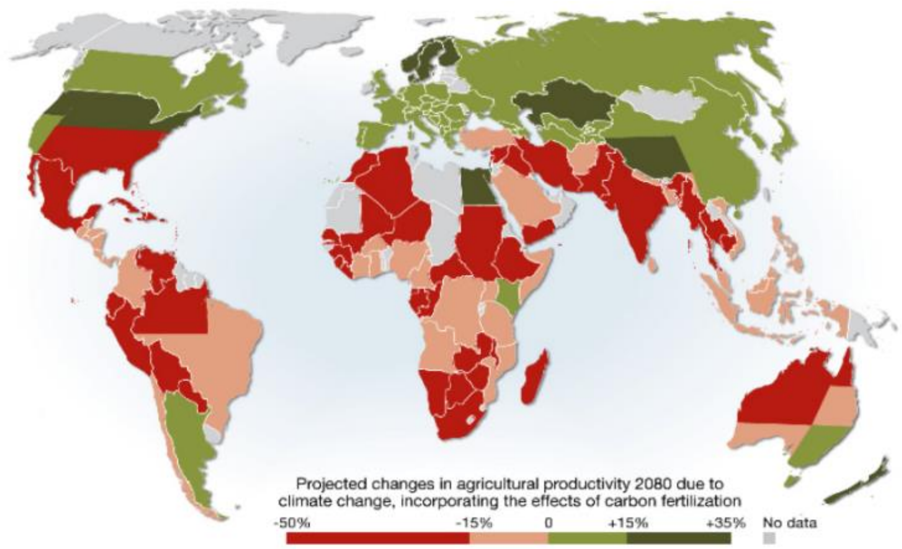


Figure 3.1. Projected loss of agricultural productivity (%) in 2080 as a result of climate change. The projection includes effects of increased temperature and altered patterns of precipitation, as well as carbon fertilisation for plants. Egypt and Kenya are the only African countries in which an increase is predicted. Figure from: Ahlenius & UNEP/GRID-Arendal (2008).

Wheat is predicted to suffer the most with a decrease in yield by as much as 72% by 2080, while grains such as maize, rice, millet and beans will be moderately affected (Adhikari *et al*., 2015). The impact on root crops such as cassava, sweet potato and potato is less clear, but not as severe as for grain crops (i.e. changes in yield range from -8 to 10%, -15% to +1% and -17% to -15%, respectively). This is one of the reasons why the introduction of root and tuber crops in the areas where the population traditionally depends largely on cereals, is one of the measures suggested (Hvoslef-Eide, pers. comm.).

A rise in temperature could reduce areas optimal for production of tea and coffee by 40%, and the production of sugarcane and cotton are also particularly susceptible to drought (CIAT, 2011a, 2011b; Adhikari *et al*., 2015). Seeing as both sugarcane and cotton are important cash crops for farmers in all study countries, as well as being a major export commodity in Uganda and Tanzania – while the same is true for tea and coffee in Kenya and Ethiopia – this could have major implications for the economy and food security. For some crops, an increase in temperature may have beneficial effects on yield, but only up to a certain threshold (e.g. up to 35˚C for highland bananas) (CCAFS, 2012; Adhikari *et al*., 2015).

3.2.2. Biotech crops with increased resilience and adaptability to climatic and environmental change

Consequently, crops that are resistant to pests and abiotic stressors such as drought (i.e. plants that can withstand long periods of low soil moisture and/or with enhanced ability to utilise water resources) are highly relevant for increased adaptability to climate change. Indeed, the annual report by FAO (2016) promoted the use of biotechnology to meet challenges of climate change faced by smallholder farmers. That being said, increased access to markets, information and credit, as well as improved management practices (e.g. water management), were considered among the most important measures (ISAAA, 2016b).

Example: Water Efficient Maize for Africa (WEMA). Maize is the most widely grown staple in Africa and provides food for over 300 million people (Siamachira, 2016). In Kenya, 40% of all crop areas are dedicated to the cultivation of maize, thus making it the country's most important crop (Abate *et al*., 2015). WEMA is a public-private partnership (PPP) led by AATF and Monsanto, which receives funding from the Bill & Melinda Gates Foundation, the Howard G. Buffett Foundation and USAID. WEMA contains two stacked genes, one of which encodes a Bt toxin (Box 3.1) for resistance against stem borers, while the other encodes a "cold shock"-protein (*CspB*) from the bacterium *Bacillus subtilis* which confers drought tolerance (AATF, s.a.-a). The transgenic seeds are to be distributed royalty-free and are estimated to increase maize production by 2 million tonnes, which is the equivalent of feeding 14-21 million people (AATF, 2012a; Monsanto Company, s.a.-a).

Box 3.1. The *Bacillus thuringiensis* (Bt) toxin. The Bt toxin is a naturally occurring compound produced by the soil bacterium *Bacillus thuringiensis* (see Palma *et al*., 2014 for a review).Once ingested by an insect, the protein becomes activated in the intestinal milieu and a crystal-like structure is formed that punctures the gut, thus killing the insect rapidly. The Bt toxins are considered harmless to humans and relatively benign to the environment. Over 200 types of Bt proteins have been identified, many of which are specific to certain species or genera of insects, which works to limit non-target effects (Schnepf *et al*., 1998; de Maagd *et al*., 2003; ISAAA, 2016c).

3.2.3. Biotech crops for sustainable agriculture and preservation of biodiversity

Biotech crops that are able to grow in suboptimal soils (e.g. high acidity, aluminium toxicity and salinity) represent a way in which yield can be increased without expanding areas devoted to agriculture, thus alleviating the need to convert biodiverse habitats into cultivated areas (Carpenter, 2011). Additionally, pest and disease resistant crops have been shown to reduce the environmental impact of pesticides. For instance, the adoption of Bt maize has reduced the use of insecticides in Spain (65%), the United States (8%), South Africa (10%) and the Philippines (5%) (Qaim, 2009). The benefit appears even greater with Bt cotton, where an estimated 65%, 47%, 36% and 33% reduction in pesticides have been reported in China, Argentina, United States, and South Africa, respectively. All-in-all, this is believed to have reduced the environmental impact by 25% (Brookes & Barfoot, 2006; Barrows *et al*., 2014). Furthermore, HT crops can facilitate low or no-tillage farming which serves many benefits, including reduced (i) soil erosion, (ii) pollution run-off, (iii) water loss due to evaporation and run-offs, (iv) mechanisation and fuel use, and (v) release of greenhouse gases found in the soil; all of which may decrease the agricultural carbon footprint and overall production costs (Meijer & Stewart, 2004; Derpsch *et al*., 2010; Klümper & Qaim, 2014; Trigo, 2016).

One way in which biodiversity can be preserved is by focusing research efforts on orphan crops, so called because such crops have been – for one reason or another – underexploited during the course of domestication (Bhattacharjee, 2009). In fact, out of the 7000 plant species that have been domesticated, only 30 make up the greater portion of global agriculture (Bhattacharjee, 2009). Consequently, research and development (R&D) and the global agricultural trade market have concentrated on these species, which has reduced agricultural biodiversity and narrowed the genetic base of crop resources (Collins & Hawtin, 1999; Bhattacharjee, 2009).

Thus, research that focuses on orphan crops can help conserve genetic and agricultural diversity, as well as increase food security as millions of African smallholder farmers rely on such crops (e.g. cassava and sweet potato) (Bhattacharjee, 2009). However, as with conventional breeding, biotechnological approaches have displayed a tendency to focus on a few select species (e.g. canola, cotton, maize and soya), because the market for these crops are large enough for the seed companies to expect returns for their investments (Hvoslef-Eide, pers. comm.). In this respect, it is promising that an increasing number of orphan and pro-poor crops are currently in the biotechnology pipelines in several countries. The challenge is to get the rest of the global market and multinational companies on board, and find ways in which the technology can move beyond the stage of confined field trials.

3.3. Relieving crop losses due to pest and diseases

Pest and diseases severely impact the productivity and yield of many East African crops, and the incidence of pest and diseases was considered among the biggest constraints to East African agriculture by stakeholders and farmers alike (Table 2.1 and Table 2.2, respectively).

Yield losses in cassava can creep up to 50%, whereby one of the major culprits is Cassava Mosaic Disease (FAO, 2010), which describes a combination of viral pathogens which due to synergistic effects exceed the effect of a single virus (see Chapter 5, section 5.3.3 for more information) (Hull, 2013). Maize is susceptible to a range of pests, including stem and ear borers, armyworms, cutworms, grain moths, beetles, fungal diseases and different viruses (Ortega, 1987). In cowpea, which is a particularly nutritious and economically important grain legume, losses due to pests and weeds can be as high as 90% (Mignouna *et al*., 2010). Bananas, which are major staple food and cash crop in the East African highlands and Great Lakes region, are threatened by several diseases, including panama disease, black Sigatoka leaf spot disease, banana streak virus, nematodes and Xanthomonas wilt disease (see Chapter 6). Striga, or witchweed, is an obligate parasitic plant whereby the seed latch onto the roots of the host plant – including maize, sorghum, millet and cowpeas – and "sucks" them dry (ICSU, 1984). Cotton is heavily attacked by pests such as African bollworm (*Helicoverpa annigera*) (van den Berg & Cock, 2000).

Many East Africa farmers do not have access to or the adequate resources to apply chemicals to control pests and pathogens (Odame *et al*., 2002; Salami *et al*., 2010). For instance, a mere 8% of Ethiopian small-scale farmers can afford to buy and apply pesticides (Azadi *et al*., 2011). Furthermore, the transmission and spread of pathogens becomes exacerbated due to small and closely packed landholdings. Consequently, resistant varieties obtained through genetic engineering may provide a powerful tool to combat yield losses due to pests and pathogens, since the resistance is present in the seeds/planting materials.

3.3.1. Example 1: Bt cotton – revival of the Kenyan and Ethiopian textile industry?

Mass production of Bt cotton could represent a multi-billion Kenyan shilling project (Andae, 2016a). Dr. Charles Waturu of Kenya Agriculture and Livestock Research Organization (KALRO), who has been the appointed Principal Investigator on Bt cotton research for ten years, believes that adoption of Bt cotton could revive the Kenyan textile industry – from today's 29 000 ha, to 400 000 ha (Okinda, 2017). Additionally, adoption of Bt cotton could reduce the daily average spraying from 10 to 2 (Kenyan cotton farmers met during the farmer survey told that they had sprayed up to 12 times before harvesting), which will save on production costs, lessen exposure to potential harmful chemicals and reduce the time spent in the field (ISAAA, 2015b). Similarly, Bt cotton has also been proposed to help meet the demand of the cotton industry in Ethiopia (Tefera & Mohammed, 2015; Tefera & Tefera, 2015).

3.3.2. Example 2: Efforts to counteract potato late blight in Uganda

In Uganda, ~300 000 farmers grow potatoes as both a cash and subsistence crop (CIP, s.a.). However, losses due to potato late blight can be a staggering 60%, which amount to a 10-25% loss in farmer income (CIP, s.a.). Currently, fungicides have to be sprayed as many as 15 times to keep the disease at bay (CIP, s.a.). Adding to the severity of the issue is a new population of even more difficult-to-handle biotypes of the pathogen (CIP, s.a.). In response to the need for farmer-preferred resistant varieties, the National Agriculture Research Organisation (NARO) in Uganda and the International

Potato Centre (CIP) are carrying out field trials of potatoes expressing three resistance (R) genes (Box 3.2) from the wild relative *Solanum bulbocastanum*. The first results from the field observation have been promising; even when no fungicide was applied, the transgenic potatoes exhibited extreme levels of resistance (CIP, s.a.).

Box 3.2. Resistance (R) genes. An important type of pathogen resistance in plants is initiated by the interaction between products encoded by resistance (R) genes and the products of corresponding avirulence (*Avr*) genes (transcribed by the pathogen) (Flor, 1971; Hammond-Kosack & Jones, 1997; Cai *et al*., 2002). R-Avr interactions initiate the hypersensitive response (HR) in the plant whereby the plant cells undergo apoptosis (programmed cell death) in order to restrict the movement of the pathogen to the primary site of infection (Morel & Dangl, 1997; Marone *et al*., 2013). Following HR, a systemic acquired response (SAR) is initiated which is believed to confer broad-spectrum and systemic resistance (Głowacki *et al*., 2011; Marone *et al*., 2013). Consequently, scientists have attempted to use genetic engineering to transfer certain R genes to crop plants as a way of conferring pathogenic resistance (e.g. Gururani *et al*., 2012; Marone *et al*., 2013; Jones *et al*., 2014).

3.3.3. Example 3: The Virus Resistant Cassava for Africa (VIRCA) Project

Cassava represents the staple source of calories for over 250 million Africans and an estimated 80 kg of cassava is consumed per person yearly (IITA, 2009; Sayre *et al*., 2011). Cassava is a particularly attractive crop due to its hardiness and resilience to abiotic stressors, which allows cultivation under marginal conditions (Alabi *et al*., 2011). Furthermore, cassava requires less labour while still producing higher yields per unit land when compared to yams, wheat, rice and maize (Alabi *et al*., 2011). Alarmingly, cassava is highly susceptible to biotic stressors, such as cassava green mite, grasshoppers, cassava bacterial blight and various viruses (Alabi *et al*., 2011). For instance, between the early 1990s and 2006, cassava mosaic disease (CMD) accounted for 47% of losses in cassava production in East and Central Africa (IITA, 2009). The Virus Resistant Cassava for Africa (VIRCA) project aims to develop cassava resistant to cassava brown streak disease (CBSD) and CMD by employing pathogen-derived RNA silencing technology (Box 3.3) (Taylor *et al*., 2012). After a series of confined field trials, the project has now moved into its second phase, whereby lead events of two transgenic farmer-preferred varieties are identified using molecular and field screening (Taylor *et al*., 2012).

Box 3.3. RNA silencing. RNA silencing, or RNA interference (RNAi), is a regulatory mechanism whereby an RNA molecule, e.g. miRNA or siRNA, inhibits gene expression either by (i) inducing mRNA degradation, (ii) inhibiting translation post-transcriptionally, or (iii) causing epigenetic modifications at the transcriptional level (Duan *et al*., 2012). RNA silencing was employed in the first transgenic crop product, namely Flavr Savr tomatoes, whereby the polygalacturonase gene – which is responsible for the breakdown of pectin – was silenced using RNAi technology (Sheehy *et al*., 1988; Smith *et al.*, 1988). Additionally, RNA silencing can act as a defence mechanism against viruses, thus has been employed in transgenic plants to confer resistance to viral pathogens (Chapter 5, section 5.3.3) (Béclin *et al*., 2002; Ding, 2010; Duan *et al*., 2012).

3.3.4. Examples of conventional practices for pest management

Integrated pest management (IPM) is an approach that combines different strategies in order to increase crop production and protection, while keeping the use of pesticides to a minimum (EPA, 2016). Methods include crop rotation, intercropping, particular techniques of cultivation (e.g. pruning, debudding and hand weeding), employing pest resistant/tolerant cultivars, balancing soil fertility, carrying out field sanitation and various hygiene measures, and so forth (FAO, s.a.-b). The push-pull-system is a type of IPM which exploits the use of two different signalling molecules – one which works to repel insects from the crop (”push”), while the other attracts them to a so-called trap crop (“pull”) (Pickett *et al*., 2014). Such a system has been developed using *Desmodium uncinatum* (“push”) and Sudan gras (*Sorghum vulgare* var. sudanense) and/or Napier grass (*Pennisetum purpureum*) (“pull”) in order to repel lepidopterous pests such as stem borers from maize (Fig. 3.2) (Hassanali *et al*., 2008).

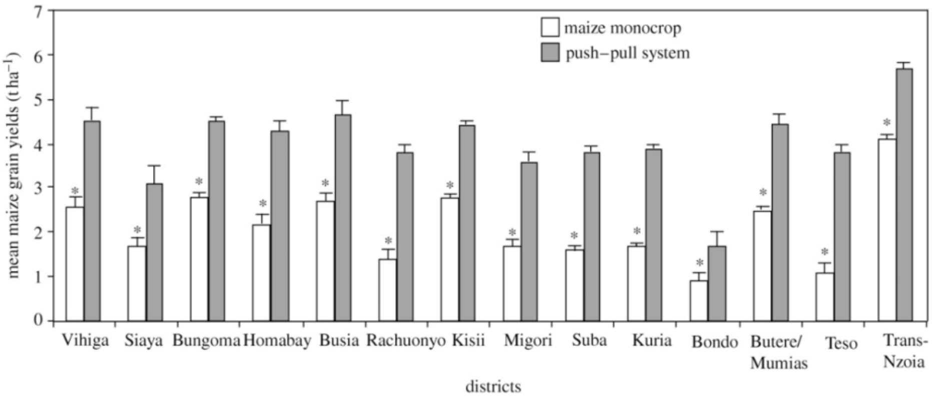


Figure 3.2. Yield differences between maize monocrops and push-pull systems in Kenya. Yield differences between push-pull systems and control plots (i.e. monocrops of maize) in different Kenyan districts during the 2005 long rains. All districts exhibited a significant difference ($p<0.05$, t-test; indicated by asterisk) in grain yield between the push-pull and control plots. Figure from: Hassanali *et al*., 2008.

Adding to the above-mentioned example, intercropping maize or other cereals with *Desmodium* can help inhibit growth of Striga (Fig. 3.3) (icipe, s.a.). The approach has other benefits as well, including improved soil fertility (due to increased nitrogen fixation by *Desmodium*) and providing farmers with supply of animal fodder (which constitutes the main use of *Desmodium*) (icipe, s.a.). Currently, more than 75 000 smallholder farmers in Ethiopia, Kenya, Tanzania and Uganda control striga using this method (icipe, s.a.).

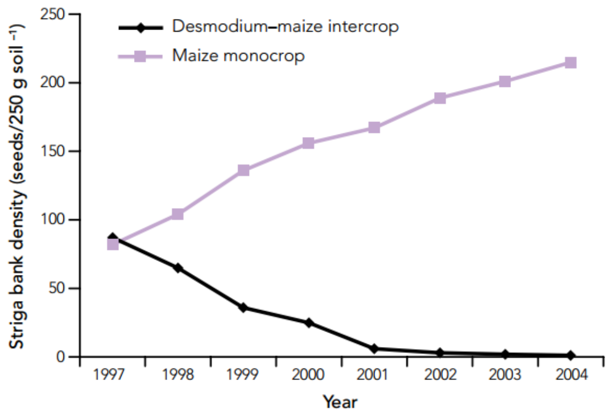


Figure 3.3. Reduction of Striga in *Desmodium*-maize intercropping systems when compared to maize monocrops. Over an eight-year period, intercropping maize with *Desmodium* reduced the amount of striga seeds found in the soil to virtually nothing. From: icipe, s.a.

As apparent from above-mentioned examples, conventional methods of disease and pest management can prove efficient in some cases and should be encouraged. However, certain conventional methods may not suffice when the pest or pathogen is particularly virulent and fast-spreading, as in the example of Banana Xanthomonas Wilt (Chapter 6). Furthermore, conventional methods can be time-consuming, laborious, affect the quality of produce negatively, and may require awareness, educational measures and resources to be implemented efficiently (Bagamba *et al.*, 2006; Kagezi *et al.*, 2006). In such cases, biotech crops with resistance to various pest and diseases may offer an attractive part of the solution.

3.4. Biotech crops for increased productivity & yield

***African soils are characterised by low productivity and yield*.** The potential crop productivity in Africa – i.e. the measure of the amount of agricultural output per agricultural input (Michel Serres Institute for Resources and Public Goods, 2012) – is relatively high due to the amount of incoming solar radiation and high temperatures (IAC, 2004). However, African soils are considered unfavourable for cultivation due to lack of nutrients and inadequate water availability, which in many cases is a result of inappropriate land use, inadequate management of resources and lack of inputs (Gilbert, 2012; Bationo *et al.*, 2012). For instance, in 2001, the average crop production per hectare in Sub-Saharan Africa was 54% of the global average (FAO, 2004b). More specifically, in Ethiopia, FAO estimated that the productivity of cereals was as low as 1.1 tonnes per ha (t/ha) in 2008 (as cited by Azadi *et al.*, 2011). Consistent with such findings, 91.3% of farmers and 93.6% of stakeholders considered low crop productivity and yield as an important or very important challenge to East African farming (Chapter 2, Table 2.1 and 2.2).

One of the main ways to increase productivity and yield is via the application of fertilisers (e.g. Edmeades, 2003). However, many smallholder farmers do not have the adequate knowledge of nutrient dynamics or simply do not have sufficient access or resources to acquire and apply fertilisers, thus depleting the soil of nutrients (Odame *et al.*, 2002; IAC, 2004; Morris *et al.*, 2007). For instance, in 2013, the average rate of fertiliser application were 52.5, 19.2, 4.7 and 2.2 kg/ha on arable land in Kenya, Ethiopia, Tanzania and Uganda, respectively, which is significantly lower than the world average of 119.9 kg/ha (World Bank, 2016). As a result, mineral fertiliser subsidies have become increasingly popular and some African countries spend as much as 70% of agricultural funds on such subsides (Kotchi, 2015). However, subsidy programmes are considered only a short-term solution as they do not promote long-term improved soil fertility or sustainable food security, and serve little economical profit (Kotchi, 2015). Besides, fertilisers can pose ecological threats including reduced humus content and biodiversity in the soil, as well as increasing acidity and release of greenhouse gases (IAC, 2004; Kotchi, 2015).

Biotech crops for increased yield and productivity. Consequently, there is a need for a long-term solution for increasing productivity and yield in East Africa. Biotech crops do not necessarily come with inherently higher yields, but reduced losses due to biotic and abiotic stressors will work to increase harvest. Other active areas of research are the development of plants with increased photosynthetic activity/rate (e.g. Kromdijk *et al*., 2016), or that can acquire and assimilate nitrogen from fertilisers more efficiently (e.g. Shrawat *et al*., 2008). Such biotech crops will increase yield in areas where access to fertilisers is limited (including many East African farming systems), reduce nitrogen run-offs into e.g. surface waters, lower production costs, and have beneficial effects on the environment (Shrawat *et al*., 2008; Carpenter, 2011).

Example: Nitrogen-USE Efficient, Water-Use Efficient and Salt-Tolerant (NEWEST) Rice Project. During the past two decades, the consumption of rice has steadily increased in Sub-Saharan Africa, including in the East African region (EUCORD, 2012). However, the current rice production is characterised by low yields and over 40% is imported annually, which accounts to over US$5 billion (AATF, s.a.-b). Drought and nitrogen deficiency in the soil are considered the two major constraints of rice production, thus NEWEST rice contains transgenes for enhanced nitrogen-use and water-use efficiency, as well as for salt tolerance. Currently, field trials are being carried out in Uganda (NARO), Ghana and Nigeria, and the first results are promising – the transgenic rice exhibited an average increase in yield by 19% compared to conventional rice (AATF, s.a.-b; Arcadia Biosciences, 2015).

Conventional methods. That being said, biotech crops are but one of several technologies and methods that can help enhance agricultural productivity, including increased mechanisations, better tools, and improved soil, water and nutrient-management through means of run-off management, water harvesting, supplementary irrigation, conservation tillage and application of organic and inorganic fertilisers (IAC, 2004).

3.5. Reduced post-harvest losses

Post-harvest loss (PHL) is defined as qualitative and quantitative loss of food along the supply chain from harvest until consumption or other end uses (De Lucia & Assennato, 1994; Hodges *et al*., 2011). PHL is an often forgotten, but major limiting factor for food production in Africa, especially for farmers that rely on staple foods for their disposable income (World Bank, 2011a). Indeed, 81.3% of the surveyed farmers regarded PHL as challenging or very challenging to their farming (Chapter 2, Table 2.2), especially by the Kenyan farmers (Appendices 1, Appendix D, Table D.1.1).

PHL occurs at every step of the food chain and can be a result of natural decay; pest and diseases (PHL due to insects is estimated to constitute 15% of the world's production, of which most of the loss occurs in the developing world due to the favourable climate for infestation by insects and fungus; Herrera-Estrella & Alvarez-Morales , 2001); the process of harvesting, field handling, storage (or lack thereof), packaging, transport, marketing and distribution practices (FAO, 1989; World Bank, 2011a); mismanagement of stocks and associated financing (World Bank, 2011a); and challenges associated with ownership, control and payment of storage (World Bank, 2011a). Table 3.2 shows examples of causative factors of PHL in maize (IAC, 2004).

Table 3.2. Causes of Post Harvest Losses (PHL) in maize (in % of total losses) for small, medium and large-scale farms in Kenya, Uganda and Tanzania.							
Causes of PHL	**Kenya**			**Uganda**		**Tanzania**	
	Small	**Medium**	**Large**	**Small**	**Medium**	**Small**	**Large**
Transporting on poor roads	0	5	-	11	6	13	-
Lack of storage	6	0	-	18	13	13	13
Pest infestation	17	18	37	25	32	40	50
Poor quality of storage facilities	28	14	-	20	16	23	25
Impact of weather	33	58	50	29	28	10	13
Spillage	17	5	13	4	6	-	-
Total	100	100	100	100	100	100	100
Table from: World Bank (2009).							

Though it is difficult to estimate PHL, reports have shown that losses may range from 10% to 100% in African countries (Amleson, 2004; IAC, 2004). Loss of fruit, vegetables and root crops – including important East African crops such as sweet potato, plantains and bananas – can be 50% or more, and even moderate decay can severely affect the nutritional and commercial value (IAC, 2004). Grain losses are less severe, but still substantial – prior to processing, physical losses can amount to 10-20% and an estimated economic loss of US$ 1.6 billion incurs every year in the Eastern and Southern African region (i.e. 13.5% of the total value of grain production) (World Bank, 2011a). Consequently, PHL results in food insecurity, loss of market opportunities, higher food prices, decreased nutritional value, and wastage of expensive inputs such as fertilisers, irrigated water and agricultural labour (World Bank, 2011a). Thus, reducing PHL will benefit the producers (especially the rural poor), consumers and the economy of the country as a whole. For instance, it has been estimated that a 1% reduction of PHL would amount to an annual gain of US$40 million (World Bank, 2011a). Furthermore, it is in many respects more cost-effective and environmentally sustainable to alleviate PHL than to increase crop production and intensify cultivation, especially in times when food prices are high (World Bank, 2011a).

Biotech crop for reduced post-harvest loss (PHL). An obvious solution for reducing PHL is disease and pest resistant GM crops. Additionally, shelf life and storage capability can be increased by reducing metabolism and the process of ripening in fruits and vegetables after harvest (e.g. bananas, papaya, guava and tomatoes). Ripening is regulated by the hormone ethylene, thus by turning off or decreasing the expression of genes involved in the ethylene production pathway (e.g. ACC synthase or ACC oxidase expression) or by modifying receptors for ethylene, ripening can be postponed (Hansen, 1943; Kidd & West, 1945; Burg & Burg, 1962; Hvoslef-Eide *et al*., 1995; ISAAA, 2016d).

Other measures for reduced post-harvest loss (PHL). As already touched upon, PHL can also be a result of lack of knowledge and resources and/or governance-related factors (World Bank, 2011a). Consequently, governments should adopt policies that favour development of knowledge and expertise within the production-market chain (which is limited in many African countries), as well as allocate more resources for developing basic infrastructure (IAC, 2004). Furthermore, local processing has been shown to alleviate PHL, as well as increasing the economic value of crop products (IAC, 2004).

3.6. Increased nutritional value: Consumer health and welfare

The diet of many rural poor and smallholder farmers consists of a limited number of food items which do not necessarily meet the caloric target and/or cover the full range of vitamins, minerals and proteins required to meet food secure levels (Osuntokun, 1976; FAO, 1997). Furthermore, the lack of appropriate infrastructure, war and conflict, aids and other diseases, and poor access to health services further add to the issue of malnutrition (Fanzo, 2012).

GM crops can offer a way to help meet the caloric demands through increased yields and productivity, as well as vitamin, mineral and protein deficiencies by means of biofortification (Welch, 2005; ISAAA, 2007). For instance, between 15-32% of Ugandan children under the age of 5 suffer from vitamin A deficiency, while 73% are anaemic (Banana21, 2016). This deficiency can be explained by the fact that bananas – which represent the major staple food crop in the country – are low in pro-vitamin A and iron (Banana21, 2016). Currently, NARO and Queensland University of Technology in Australia have identified a range of genes from different cultivars of banana that are either involved in the biosynthesis of provitamin A or the accumulation of iron. For instance, the phytoene synthase gene (*APsy2a*) –which is involved in the synthesis of pro-vitamin A carotenoids –from the high provitamin A cultivar 'Asupina' is now being used in advanced lines. Hitherto, certain lines have shown levels of provitamin A up to four times higher compared to controls during field trials (Namanya, 2011; Banana21, 2016).

Similarly, cassava provides <30% of the minimum daily requirement of protein and 10-20% of iron, zinc and vitamin A (Sayre *et al*., 2011). In an attempt to address this issue, the BioCassava Plus-project has established transgenic lines with increased levels of nutrients and micronutrients, as well as traits for increased shelf life, resistance to viral disease and reduced levels of toxic cyanogenic glycosides (Sayre *et al*., 2011). Indeed, biotechnological methods can also be used to reduce the amount of anti-nutritional factors, such as the before-mentioned cyanogenic glycosides (Conn, 1980). If careful processing is not performed, this compound may cause severe diseases such as tropical ataxic neuropathy and konzo (Oluwole *et al*., 2000; Jørgensen *et al*., 2005). However, processing will decrease the nutritional value of the food item (Onabolu *et al*., 2002). By using antisense technology, the two genes encoding the enzymes responsible for initiating the production of cyanogenic glycosides were silenced, leading to a 92% reduction in the leaves and tubers of the cassava (Jørgensen *et al.*, 2005).

3.7. Early maturity

Another attractive transgenic trait listed by surveyed farmers from all study countries was early maturity. Maturity is important for yield and quality of produce, and it is often desirable to allow the crop to go through the entire growth season to allow for optimal productivity (Acquaah, 2012). However, early maturity can be advantageous under certain conditions, for instance as a way of circumventing abiotic and biotic stressors like disease, pests, low rainfall and drought (Acquaah, 2012). For instance, early maturity is a major breeding goal in maize as it can improve sustainability and increase stability of production and yield when the crop is cultivated in marginal zones (e.g. at high altitudes or during drought) (Peter *et al*., 2002). Additionally, early maturity can be particularly useful in multicropping systems as a way of allowing several crops to be grown in a single production season (Acquaah, 2012). However, early maturity comes with certain demerits, including reduced economic yield in certain species (e.g. maize and rice), and it is negatively correlated with factors such as fibre length in cotton (Acquaah, 2012).

Crop maturity is influenced by various factors, including genotypic effects, level of moisture, temperature and photoperiod (Acquaah, 2012). The circadian clock regulates many physiological and biological processes and responses in plants, including several agronomic traits (e.g. growth rate, development, maturity and reproduction) (Faure *et al*., 2012). For instance, the circadian clock measures photoperiod and influence diurnal and seasonal flowering, and as a consequence, is very important for agricultural productivity (Zhang *et al*., 2015). Several genes and transcription factors are involved in the intricate network and feedback loops making up the circadian clock. One such gene is the flowering-promoting factor (*fpf1*) which has been cloned from *Arabidopsis thaliana* and been used to induce early maturity in e.g. transgenic rice and maize (Kania *et al*., 1997; Peter *et al*., 2002; Xu *et al*., 2005).

3.8. Concluding remarks

Biotech crops could offer part of the solution to many of East Africa's most pressing issues, including enhanced adaptability and resilience to climatic and environmental change (e.g. varieties for drought-tolerance); promoting sustainable agriculture and conserving biodiversity (e.g. crops that can grow in suboptimal soil); relieving losses caused by pests and diseases; reducing post-harvest loss; and increasing nutritional value to meet matters of malnutrition – all of which can help enhance productivity and yield, and ultimately have positive impacts on poverty alleviation, food security, health and socio-economic aspects.

However, the development of biotech crops is not without its constraints and limitations; certain techniques and protocols used for transformation and regeneration are far from optimised and may not be applicable to farmer-preferred varieties. Furthermore, certain traits are very complex and involve a range of genes and gene interactions – perhaps even epigenetics – which can be challenging to manipulate for the purpose of transgenic R&D. For instance, the relatively moderate success of Monsanto's DroughtGard maize in the US can partly be explained by the complexity of drought-tolerant traits (Gilbert, 2014; Ricroch & Henard-Damave, 2015; Monsanto Company, s.a.-b). In fact, insofar, conventional methods have been considered more successful at acquiring drought-tolerance and nitrogen-use efficiency at a faster rate than for transgenic methods (Gilbert, 2014).

Additionally, biotech projects need to consider that, in many cases, the ultimate question is often whether the crop can deliver in terms of yield and profit (though this is far from the only characteristics important to farmer's choice; e.g. see Chapter 24, section 24.1). For instance, Golden Rice (i.e. a transgenic rice with increased levels of vitamin A) has so far shown inconsistent and lower yields across locations compared to conventional rice varieties, which has led to farmer reluctance (Dubock, 2014). Indeed, just like any crop variety, the performance of biotech plants may be significantly affected by environmental variables and other confounding factors such as the plant's developmental stage, variation in gene control, and disease pressure (e.g. GM bananas; Chapter 6). Such factors may limit the successful widespread adoption of a certain crop variety. However, scientists and companies are expected to take such issues into consideration by testing the variety across a range of environmental conditions to ensure stability of transgene expression and adequate performance in order to obtain permission from governments.

Thus, it is absolutely pivotal to recognise that biotech crops are not a silver bullet, but rather a complimentary tool that should work alongside traditional breeding; good agricultural practices (GAP); integrated pest management (IPM); increased mechanisation and better tool use; improved irrigation and water management; enhanced access to credit, markets and inputs (e.g. fertilisers); and development of other sectors such as health and education.

Chapter 4. The Biotech Pipeline and Research Capacity within Agricultural Biotechnology in East Africa

The following crops and transgenic characteristics are currently in the biotechnology pipeline in East Africa: Maize, sorghum, bananas, sweet potatoes, *Ensete*, cowpea, cassava, yams and cotton; with traits such as insect and disease resistance, drought and salt tolerance, nitrogen-use efficiency and biofortification (Table 4.1) (Chambers *et al*., 2014; James, 2015; agricultural researchers at IITA, KALRO and NABRC-EIAR, pers. comm).

Table 4.1. The Biotech Pipeline in Kenya, Uganda, Tanzania and Ethiopia.

Country	Crop	Trait	Institutions involved	Stage as of 2015/2016
Kenya	Maize, *Zea mays* L.	Drought Tolerance	African Agricultural Technology Foundation (AATF), International Maize and Wheat Improvement Center (CIMMYT), Kenya Agricultural & Livestock Research Organisation (KALRO)	6th season confined field trials (CFT) completed
		Water-Efficient Maize for Africa (WEMA)-Insect Resistance (Bt maize-MON810)	AATF, CIMMYT, KALRO	Conditional approval for environmental release; to conduct National Performance Trials (NPTs)
		Stacked maize event for Bt (MON810) and drought (MON87460)	AATF, CIMMYT, KALRO	1st season CFT completed
	Cotton, *Gossypium hirsutum* L.	Insect resistance	KALRO, Monsanto	Conditional approval for environmental release; to conduct NPTs
	Cassava, *Manihot esculenta* Crantz	Cassava mosaic disease (CMD)	KALRO, Danforth Plant Science Center (DDPSC), International Institute of Tropical Agriculture (IITA)	2nd season CFT completed
		Cassava Brown Streak Disease (CBSD) introgression into CMD tolerant background materials	KALRO, DDPSC, IITA	1st season CFT completed; regulatory trial ongoing (1st season)

		Cassava brown streak virus (CBSV) and African cassava mosaic virus (ACMV) resistance	Masinde Muliro University of Science and Technology (MMUST)	1st season CFT completed
	Sweet potato, *Ipomoea batatas*	siRNA resistance to Sweet potato virus disease	KALRO-Kakamega, DDPSC	1st season CFT completed
	Sorghum (ABS), *Sorghum bicolor* Moench	Enhanced pro-vit A levels; Bioavailable zinc and iron	Africa Harvest, Pioneer Hi-Bred, DuPont business, KALRO	7th season CFT completed
		Resistance against Striga[1]	Kenyatta University	Contained laboratory and screen house
	Cowpea, *Vigna unguiculata*[2]	Drought tolerance	KALRO	Undergone laboratory and screens house; awaits CFT
	Gypsophila, *Gypsophila paniculata*	Pink colouration of petals	Danzinger, Flower Farm, Israel	Review for environmental release
	Banana, *Musa* spp.	Banana Xanthomonas Wilt (BXW) resistance	KALRO, IITA	1st season CFT ongoing
Uganda	Maize, *Zea mays* L.	Drought tolerance and insect resistance; stacked events	National Agricultural Research Organisation (NARO), AATF, Monsanto, CIMMYT	Multi-location trial planted in July 2016

		Insect resistance	NARO, AATF, Monsanto, CIMMYT	4th season CFT ongoing
	Banana, *Musa* spp.	Bacterial wilt (BXW) resistance	NARO, IITA	Multi-location trial
		Nutrition enhancement (iron and provitamin A)	NARO, Queensland University of Technology (QUT)	In staggered planting systems
		Banana parasitic nematode resistance	NARO, University of Leeds	2nd season CFT ongoing
	Cassava, *Manihot esculenta* Crantz	CBSV resistance	NARO, DDPSC	1st season CFT -
	NEWEST Rice, *Oryza sativa*	Nitrogen-use efficiency/Water-usese efficiency	NARO, AATF, Arcadia Biosciences	3rd season CFT harvested
	Potato, *Solanum tuberosum*	Late blight resistance	NARO, International Potato Center (CIP)	4th season CFT ongoing
Ethiopia	Cotton, *Gossypium hirsutum* L	Insect-resistance (Bt)	Ethiopia Institute of Agricultural Research (EIAR), JK Agri Genetics-India	Multi-location trials
	Ensete ventricosum	BXW-resistance	National Agricultural Biotechnology Research Center (NABRC-EIAR), IITA Kenya	Contained laboratory and screen house
Tanzania	Maize, *Zea mays* L.	WEMA	AATF, Monsanto, CIMMYT, Ministry of Agriculture, Food Security and Cooperation (MAFC), Tanzania Commission for Science and Technology (COSTECH)	1st season CFT ongoing
Table adapted from James (2016) and ISAAA (2017). [1]Sithole-Niang *et al*., 2004; Kingiri & Ayele, 2009; confirmed by Dr. Richard Okoth Oduor; [2]confirmed by Dr. Kenneth Monjero (KALRO).				

4.1. Research facilities and capacity: Kenya

The scientific capacity in Kenya has gradually been strengthened over the years, especially with the establishment of the Kenya Agricultural & Livestock Research Organisation (KALRO) (formerly Kenya Agriculture Research Institute, KARI) and the Biosciences Eastern and Central Africa (BecA) central hub (located at the International Livestock Research Institute, ILRI, Nairobi) (Chambers *et al.,* 2014). Additionally, many public universities, including the University of Nairobi and Kenyatta University, boast cutting edge research facilities. According to Chambers *et al*. (2014), over 100 scientists from both public and private institutions are engaged in advanced biotech R&D.

4.2. Research facilities and capacity: Uganda

During the past 15 years, the capacity in terms of both human resources and infrastructure has improved in Uganda (Chambers *et al*., 2014). For instance, the National Agricultural Research Organisation (NARO) contains two advanced laboratories, while several universities now offer advanced facilities and/or biotech training programs for students (Chambers *et al*., 2014). Furthermore, three private laboratories are carrying out and commercialising tissue culture in banana, coffee, sweet potatoes and pineapple (Chambers *et al*., 2014). Additionally, capacity building initiatives (e.g. the Program for Biosafety (PBS); see 7.2.4 for more information) have helped develop the competence of scientists, regulatory authorities and biosafety inspectors (Chambers, 2013). Chambers *et al*. (2014) report that >70 students and researchers exhibit appropriate training for conducting agro-biotech research.

4.3. Research facilities and capacity: Tanzania

The research capacity within biotechnology in Tanzania is considered modest, but has been growing in recent years. Several agricultural research institutes and a few universities now have both human and infrastructural capacity for R&D (e.g. institutes in Mikocheni, Uyole, Horti Tengeru, Ukiriguru, and Mlingano; and Sokoine University of Agriculture and University in Dar es Salaam) (Chambers, 2013; Chambers *et al*., 2014). Still, most of the research constitutes tissue culture and micropropagation, while genetic transformation is still at its infancy (Chambers *et al*., 2014). In an attempt to increase capacity, the Tanzania Commission for Science and Technology (COSTECH), the National Biotechnology Advisory Committee (NBAC) and the Tropical Pesticide Research Institute (TPRI) have been established in recent years. As per 2014, around 48 researchers were engaged in R&D within agricultural biotechnology (Chambers et al., 2014).

4.4. Research facilities and capacity: Ethiopia

Key Ethiopian institutions include the Ethiopian Institute of Agricultural research (EIAR), Addis Ababa University, the National Veterinary Institute, the Institute of Biodiversity Conservation, and the International Livestock Research Institute (ILRI) (Chambers *et al*., 2014). Research has mostly been confined to tissue culture, but a biotechnology institute at Holleta, which house genomic research facilities, is nearing its completion (Kiome, 2015; EIAR researchers, pers. comm.). Agricultural universities, such as in Hawassa and Mekelle, are establishing facilities and competence to further engage and provide biotechnology education at Master and PhD levels (Hvoslef-Eide, pers. comm.).

Chapter 5. Health and Environmental Concerns Associated with Genetically Modified (GM) Crops in East Africa

Concerns associated with potential health and environmental effects of GM crops include, but are not limited to, (i) allergenicity and toxicity; (ii) cancer, sterility, obesity, asthma, autisms, and premature adolescence, aging and death; (iii) development of antibiotic resistance; and (iv) environmental impacts such as the effect of gene flow on non-target species, biodiversity and traditional crop varieties (e.g. Alteri & Rosset, 1999; Third World Network, 2002; Smale & De Groote, 2003; African Union, 2006; Kimenju *et al*., 2011; Mtui, 2012; Daily Nation, 2015; Ongu, 2015). Such concerns became evident during the perception studies, whereby both farmers and other stakeholders expressed high level of concerns related to possible negative health and environmental effects, and further believed that the prospect of such potential risks were a cause of controversy among the public and governments (see Chapter 24). Where do such fears stem from, what impact do they have on regulatory decision-making, and are any of them justifiable? If so, what preventative measures can be implemented to reduce or avoid such risks?

This chapter will address potential health and environmental concerns that are relevant to the current biotech pipeline in East Africa, and that have been of particular influence on the perceptions and decision-making associated with biotech crops in the region. Consequently, certain topics that are mostly pertinent in the context of Westernised farming will be foreclosed. For instance, despite its importance, the ongoing debate on the development of glyphosate-resistance and the rise of "superweeds" will only be mentioned in passing. The reasoning behind this is based on the consideration that, in many cases, the promotion of herbicide resistant (HT) crops in East African small-hold farming systems would be premature as conventional weeding practices often suffice (personal correspondence with Dr. Richard Okoth Oduor). That being said, several lessons can be learnt from examples such as HT, which can be valuable in the context of biotech crop adoption in East Africa (e.g. the importance of good agricultural practices, GAP).

5.1. Allergenicity and toxicity

5.1.1. Allergenicity

The introduction of any novel food item, be it transgenic or conventional, can pose new allergenic risks. Thus, one of the most prominent concerns of consumers, biotechnology researchers and companies, and regulatory agencies is the possibility of allergenic reactions to proteins expressed in GM products (Key *et al*., 2008). Such concerns mainly relate to two factors – the possibility that genes from known allergens are inserted into crops not typically associated with allergenicity, and the possibility of creating new, unknown allergens by either inserting novel genes or changing the expression of endogenous proteins (Lehrer & Bannon, 2005; Key *et al*., 2008).

The most controversial case related to allergicinity is the incidence involving Starlink Bt maize. The variety is only approved for animal feed because the Bt protein Cry9C have a higher allergic potential due to prolonged breakdown in the human gastrointestinal (GI) tract (Taylor & Tick, 2001; UCDavis, s.a.-a). Yet, allergic potential is still considered low as the Bt protein only makes up a small fraction of the entire maize protein and the amino acid sequence does not resemble any known human allergens (Taylor & Tick, 2001; UCDavis, s.a.-a). Furthermore, processing is believed to degrade most of the protein, thus consumers would only be exposed to extremely small quantities if it was to be found in food items (Pollack, 2000; Bucchini & Goldman, 2002; Starlink Corn , 2013). Still, when the Cry9C protein was found in corn products in supermarkets and restaurants in the US, Japan and South Korea in 2000, over 300 products were recalled from the market (Pollack, 2000; Taylor & Tick, 2001). In the aftermath of the incidence, the US Center for Disease Control found no occurrences of allergic reactions (CDC, 2001).

5.1.2. Toxicity

If a transgene encode a toxic product which is absorbed systematically by a host, it could have toxic effects (Key *et al*., 2008). The most infamous study related to toxicity was conducted by Ewen & Pusztai (1999) who investigated the effect of lectin-expressing GM plants on rats. Lectins are carbohydrate-binding defence proteins active against bacteria, fungi, insects, nematodes and grazing cattle (Lam & Ng, 2011). Consequently, scientists have been interested in employing lectins to create pest resistant transgenic plants (Ferry *et al*., 2006). However, unprocessed food products containing lectins may be toxic to humans and animals as the proteins can bind to receptors in the gut, thus extensive toxicity testing would be required (see 5.1.3) (Van Damme *et al*., 1998).

Ewen & Pusztai (1999) found that rats fed with GM potatoes expressing the Snowdrop (*Galanthus nivalis*) lectin agglutinin (GNA) had damaged gut mucosa compared to control rats. However, this effect was not observed in rats that were only fed lectins. Thus, the authors concluded that it was the process of the genetic engineering itself or the remainder of the construct (e.g. the CaMV35S promoter, see Box 5.1.) that gave rise to the observed effects. Ewen & Pusztai hypothesised that lymphocytes could recognise the genetically modified components as a non-self which caused an immune response to be elicited. However, the paper was criticised by, amongst others, the Royal Society of Medicine which argued that the design and execution of the experiment and the data analysis was flawed (for instance, the number of rats per test group was inadequate for obtaining statistically significant data), and that “no conclusion should be drawn from it” (Key *et al*., 2008).

5.1.3. Assessing allergenicity and toxicity: Are current methods of assessment sensitive enough, and are developing countries able to meet the standard requirements?

Before a GM product can be released to the market, detailed analysis of allergenicity and toxicity must be conducted (Goodman *et al*., 2008). Testing of allergenic potential involves, amongst others, comparing the transgenes with known allergenic proteins (Key *et al*., 2008). Toxicology testing is usually conducted in accordance with the OECD 408 Guidelines (OECD, 1998), and often involves a feeding study whereby pure chemicals are administered to rats at low, moderate and high doses over a 90-day period (Malarkey, 2003; Delaney, 2015). Thus far, no cases of toxicity or allergenicity associated with GM products have been reported (Delaney, 2015). However, there have been examples where allergenic reactions have been demonstrated during safety testing, but this has been followed by an immediate halt of further work (Nordlee *et al*., 1996; Prescott *et al*., 2005).

The current tests are considered efficient at determining whether the transgene originates from an allergenic source; whether it will react with antibodies in the serum; and if the novel gene encodes properties similar to known allergens (Key *et al*., 2008). However, the assessment of allergenic potential is complex and at times problematic, and different guidelines and experimental designs for testing exists (WHO & FAO, 1991; FDA, 1992; Goodman *et al*., 2008). Additionally, reactions are likely to manifest themselves later on as allergies often develop by repeated exposure over time (Royal Society of Canada, 2001; Goodman *et al*., 2008; UCDavis, s.a.-a).

Furthermore, how well equipped are developing countries in carrying out allergicinity and toxicity testing, particularly so when dealing with novel second-generation crops meant for human consumption? Many developing countries do boast good track records in safety testing (Adenle, 2011). Furthermore, certain safety assessments do not require major resources and equipment, for instance whereby literature searches and bioinformatics tools are used (Delaney, 2015). However, studies on *in vitro* digestion, acute and repeated dose toxicology, compositional studies and animal feeding studies are often time-consuming and resource-dependent (Delaney, 2015). In such cases, the international community and joint efforts through regional harmonisation can play an important role in increasing the capacity for safety testing through sharing of best practice, expertise and resources.

5.2. Other health concerns: Emphasis on the Séralini-paper

Various claims have been made about the possible association between GM food products and increased risk of cancer, obesity, sterility and other health-related issues in animals and humans (e.g. Makanya, 2004; Gab-Alla *et al*., 2012; Foss, 2012; Walia, 2014). Such concerns were clearly reflected in the opinions of farmers during the perceptions surveys, whereby many associated the intake of GMOs with cancer, diabetes, obesity and increased growth, and premature aging and death. Some were of the impression that GM crops were injected with substances similar to growth hormones used in e.g. the poultry industry, and believed that those who ate such products would suffer the same fate.

The most famous, disputed and referenced paper relating GMOs to cancer is by Séralini *et al*. (2012). The study linked the intake of the herbicide-resistant Roundup Ready maize to endocrine-disruptive effects and cancer in rats (see Box 5.2 for more information about Roundup Ready). The study was heavily criticised by the scientific community due to poor experimental design, e.g. small sample size and using a rat breed that are predisposed to cancer, as well as weak, inconclusive and misrepresented data, e.g. the tumour rate did not increase in correlation with the dose of GMO fed to the rats (Mestel, 2012; Pollack, 2012; Casassus, 2013). Thus, as a consequence, the paper was retracted in 2013 (Casassus, 2013). Despite this, the article has had a massive influence on regulatory decision-making and perceptions concerning biotech crops in countries such as Kenya (further elaborated on in Chapter 7, section 7.3.1).

Why such studies or claims about potential health effects gain so much ground is not known, but could perhaps be explained by socio-economic, cultural and/or religious factor (perhaps even superstition). For instance, when claims about premature aging and death were raised by farmers, it appeared to originate from a place of ignorance. Encouragingly, when told that no scientifically-sound studies have found a link between above-mentioned health effects and GMOs, most appeared convinced that such claims were largely unfound. As one farmer said: “Fear of the unknown and trying new things can sometimes make people very poor”.

5.3. Unintended transfer of recombinant DNA and transgene interactions with human cells, bacteria and viruses

Horizontal gene transfer (HGT) describes a situation whereby genetic material moves laterally between organisms, thus is not constrained by conventional barriers of reproduction and as a result can occur between distantly related organisms (Tatum & Lederberg, 1947; Went, 1971; Keeling & Palmer, 2008). HGT has been shown to take place between a range of eukaryotic and prokaryotic organisms (though more commonly for the latter), including the human microbiome and possibly involving human cells – albeit at relatively low frequencies (Nielsen & Daffonchio, 2007; Smillie *et al*., 2011; Riley *et al*., 2013; Soucy *et al*., 2015).

It has been argued that recombinant DNA possesses certain characteristics that enable or even increase the likelihood of horizontal transfer, expression and stabilisation in a host cell (Nielsen & Daffonchio, 2007). Such unintended gene transfer is proposed to have a number of potential impacts, including the spread of antibiotic resistance genes, thus lessening the effectiveness of clinically used antibiotics; creation of novel bacteria and viruses or increased virulence of existing pathogens; and disruption of gene function due to random gene integration, which could have potential health impacts such as cancer (Ho, 2001).

5.3.1. Gene transfer from transgenic foods to human cells

In theory, transgenes can be taken up by epithelial cells of the human GI tract, though it has yet to be demonstrated in experimental studies due to the challenge of detecting such transfers (Nielsen & Daffonchio, 2007). However, laboratory experiments using mice have indicated that segments of plasmids DNA can be found transiently in leukocytes, epithelial, spleen and liver cells after ingestion (Schubbert *et al*., 1997; Schubbert *et al*., 1998). However, the study fed mice with the equivalent of ~10^{13} plasmid genomes, which is considered an extremely high amount compared to what would have been encountered under natural circumstances (see Johnsen *et al*., 2000 for an elaboration). However, such studies do indicate that (naked) plasmid DNA may be transferred to epithelial cells and other organs under optimised conditions (Johnsen *et al*., 2000).

That being said, the acidic and nucleolytic milieu of the GI tract should in theory break down the majority of chromosomal and plasmid DNA before transfer and stable integration into the epithelial cells can take place (Berkowitz, 1990; Mitten *et al*., 1996). Schubbert *et al*. (1994) found that <5% of administered DNA survived longer than 7 hours in the animal gut and that the DNA was fragmented to smaller pieces. Additionally, luminal epithelial cells are constantly shed, which limits the effects that gene transfer may have (Nielsen & Daffonchio, 2007). Furthermore, the processing of the food itself, either industrially or by private consumers, is believed to affect the integrity of the recombinant DNA (Johnsen *et al*., 2000; Pauli *et al*., 2000; Kharazmi *et al*., 2003; FSANZ, 2008).

Another consideration is the enormous genetic diversity that humans are constantly exposed to through food consumption and the microbiome, which limits the testable hypothesis that transgenic food items may have more adverse effects than their conventional counterparts (Nielsen & Daffonchio, 2007). Yet, there are several gaps in the understanding of food DNA which restricts the ability to evaluate potential risks associated with HGT, and more studies on the possibility of gene transfer of complete and partially degraded recombinant DNA under natural conditions is needed (Nielsen & Daffonchio, 2007).

Box 5.1. The CaMV35S Promoter – can it engineer humans? An opinion piece by Ho *et al*. (1999), which discussed the safety of the Cauliflower mosaic virus (CaMV) 35S Promoter used in plant transformation, gained considerable attention in relation to transgene transfer. The authors argued that GM products containing the promoter could recombine to activate dormant viruses (e.g. pararetroviruses such as Hepatitis B), give rise to novel viral strains, and/or cause large-scale genomic rearrangements and overexpression of oncogenes with the potential of causing cancer in humans. Ho *et al*. based their arguments on three considerations, namely that the promoter (i) is a hotspot for recombination (Kohli *et al*., 1999); (ii) contain domains with different tissue specificities (Turner *et al*., 1996; Noad *et al*., 1997; Hull *et al*., 2000); and iii) is promiscuous and can function efficiently in organisms ranging from bacteria, plants and animals (e.g. Assad & Signer, 1990; Battraw & Hall, 1990; Hirt *et al*., 1990). In fact, the authors suggested that the observed effects in the study by Ewen & Pusztai (1999) could have been due to the CaMV35S Promoter.

However, the *un-refereed* opinion piece was heavily criticised (see Hodgson, 2000 for an overview), for instance by Hull *et al*. (2000) who argued that the mere ubiquity of the CaMV 35S promoter was enough reason to dismiss such concerns. Hull *et al.* estimated that 10% of all cauliflowers and cabbages at the local market were infected with the virus, whereby each infected cell would contain ~100 000 copies of the viral genomes, whereas transgenic events contain 1-5 copies of the CaMV 35S promoter. Thus, the authors calculated that humans have been consuming the Cauli Mosaic Virus at quantities 10 000 times higher than those present in uninfected transgenic plants. In fact, this was the reasoning behind the US Department of Agriculture's decision to characterise the risk of using the promoter as negligible (as cited by Hodgson, 2000). Furthermore, the idea that the CaMV35S promoter could reactivate dormant viruses such as Hepatitis B was deemed improbable considering that the two viruses would never replicate in the same cells (Hodgson, 2000; Hull *et al*., 2000).

5.3.2. Transgene transfer to bacterial cells: The case of antibiotic resistance

Selectable marker genes, which usually constitute an antibiotic or herbicide resistance gene, are used to distinguish between non-transformed and transformed plants (Chong-Pérez & Angenon, 2013; Yau & Stewart, 2013). In many cases, the marker gene will remain in the end product, which has caused some to question whether such genes can be transferred to microorganisms, either from transgenic plants to soil-borne microorganisms or to human gut bacteria. The fear is that the latter could reduce the efficiency of clinically important antibiotics (Dunfield & Germida, 2004; Kleter *et al*., 2005; Chong-Pérez & Angenon, 2013; Yau & Stewart, 2013).

Studies have shown that conjugation of plasmids and transformation of bacteria can occur in the digestive system and that antibiotic resistance genes can be transferred when there is a high degree of homology and a suitable selective pressure present (Yin & Stotzky, 1997; Tepfer *et al*., 2003). However, the antibiotic genes used in genetic transformation commonly have a bacterial origin and are not widely prescribed to humans (though some are employed in animal husbandry) (Miki & McHugh, 2004). Furthermore, studies have shown that transgenes are usually broken down in the GI tract before transfer to gut bacteria takes place (i.e. in the lower part of the small intestine, caecum and the colon) (van den Eede *et al*., 2004).

Several methods for generating marker-free transgenic plants have been developed and can be employed in cases where antibiotic resistance is considered a significant obstacle for consumer acceptance (for an overview, please see e.g. Chong-Pérez & Angenon, 2013). For instance, the second-generation of Golden Rice employs the phosphomannose-isomerase (*Pmi*) gene from *E.coli* as a selectable marker. Plants that have successfully been transformed will be able to use mannose as a source of carbon (i.e. the gene product of *Pmi* allows conversion of mannose-6-phosphate to fructose-6-phosphate) (He *et al*., 2004; Golden Rice Project, s.a.). Additionally, the use of gene editing tools (e.g. CRISPR), site specific recombination systems (e.g. bacteriophage Cre-lox), transcription activator-like nuclease (TALENS) and zinc finger nucleases (ZFN) can be used to excise selectable marker genes following transformation (Thomson & Ow, 2006; Yau & Stewart, 2013; Prajapati & Zala, 2015).

5.3.3. Transgene interaction with viruses

RNA silencing is one way in which plants defend themselves against viruses (Chapter 3, Box 3.3) (Ding & Voinnet, 2007; Mlotshwa *et al*., 2008; Wadsworth & Dynoyer, 2009). Consequently, by employing pathogen-derived RNAi (i.e. a type of pathogen-derived resistance; Sanford &Johnston, 1985; see e.g. Prins *et al*., 2008 for overview), scientists have obtained virus-resistant transgenic plants, including CBSV and ACMV resistance in cassava (Abel *et al*., 1986; Taylor *et al*., 2012). As already touched upon, some fear that transgenic plants containing virus-related sequences may interact with host genomes (e.g. Box 5.1). However, a more pressing concern is the potential interaction between such sequences and superinfecting plant viruses, which could potentially result in strains that are more virulent and new diseases (Turturo *et al*., 2008).

There are three possible scenarios to consider in this aspect (Ilardi, 2014): (i) synergism, i.e. synergistic interactions between two unrelated viruses which enhances infection (Hull, 2013), for instance between the potyvirus Sweet Potato Feathery Mottle Virus and the crinivirus Sweet Potato Chlorotic Stunt Virus (Untiveros *et al*., 2007; Latham & Wilson, 2008); (ii) heteroencapsidation, i.e. whereby the infecting virus acquire the coat protein (CP) of another virus, which might confer some advantage like facilitating transfer by a certain vector (e.g. Bourdin & Lecoq, 1991); and (iii) recombination (Fleischmann, 1997).

Transgenic synergism could occur if the transgene encode a viral protein which induces the phenomenon (Latham & Wilson, 2008). For instance, some viruses encode suppressors of RNA silencing which allows the virus to overcome the RNAi defence mechanisms of the host (Burgyán & Havelda, 2011). One example is the HCPRO protein produced by potyviruses (Anandalakshmi *et al*., 1998; Soitamo *et al*., 2011). Though synergism does not give rise to new viruses *per se*, one should take the necessary precautions to avoid the phenomenon from occurring, including choosing sensible sequences (i.e. avoiding those that could induce synergistic responses) (Ilardi, 2014). Transgenic heteroencapsidation*,* upon which an infecting virus acquires a foreign CP encoded by the transgene (Ilardi, 2014), have been demonstrated under lab conditions for closely related viruses (e.g. Bourdin & Lecoq, 1991). However, seeing as there is no exchange of genetic material, the effect only last a single generation (i.e. is not sustained upon infection of a new plant) (Ilardi, 2014). Yet, to avoid transgenic heteroencapsidation, the transgene sequence can be modified, e.g. by mutating certain amino acids that facilitate transfer by the vector (Ilardi, 2014).

Recombination plays an important role in the evolution of RNA viruses (Bujarski, 2013) – which makes up the majority of plant viruses (Gergerich & Dolja, 2006) – and has been shown to occur in different transgenic lines expressing viral sequences (Aziz & Tepfer, 1999; Tepfer, 2002). In theory, recombination between the infecting virus and the transgene could result in the development of more virulent strains (Turturo *et al*., 2008; Ilardi, 2014). To minimise this risk, researchers can include stop codons or frameshift mutation in the chosen sequence to prevent expression, and/or carefully choose sequences to help avoid the potential risks of recombination (Ilardi, 2014).

5.4 Potential environmental and ecological impacts of transgene flow from biotech crops

Many environmental and ecological concerns associated with the introduction of GM crops are related to transgene flow (Kwon & Kim, 2001; Lu, 2008). Gene flow is the process by which genes move from one population to another (e.g. by cross-pollination) (Ellstrand & Marshall, 1985; Slatkin, 1987), and has been shown to occur between cultivated and wild crop varieties. For instance, Chen *et al*. (2004) found that the rate of gene flow between cultivated rice and the wild and weedy relative *Oryza rufipogon* Griff was 0.01% under natural conditions.

In respect to GM crops, gene flow is usually categorised as being intra-specific, inter-specific or occurring between the biotech crop and other organisms (Kwon & Kim, 2001). Some of the possible effect of transgene flow include (i) direct and indirect effects of toxic transgenes such as Bt toxins; (ii) development of resistance to e.g. pesticide resistance genes in target organisms; (iii) increased invasiveness in the crop itself or in its wild or weedy relatives (e.g. creation of ”superweeds”); and (iv) impacts on biodiversity and ecosystem function (e.g. loss of genetic diversity in land races and traditional varieties, effects on non-target species, and impacts on soil and water quality) (Goodman & Newell, 1985; Ellstrand *et al*., 1999; Snow, 2002; Stewart *et al*., 2003; Lu, 2008; Warwick *et al*., 2009). Additionally, transgene flow can have ethical and socio-economic implications related to issues such as GMO contamination (see Box 19.1).

The distinction between hybridisation and introgression. However, it is important to distinguish between gene flow and simple hybridisation, and the key issue which is introgression. The former constitutes production of viable offspring from an interspecific mating (Baack & Rieseberg, 2007), while the latter refers to when an allele becomes stably incorporated into the gene pool of the receiving population (Anderson, 1953; Stewart *et al*., 2003). Thus, introgression depends on a variety of factors, including the proximity between species, reproductive barriers (e.g. flowering times and fertility of the progeny), recurrent gene flow over a period of time, repeated backcrossing and several generations of hybrids, and the stable establishment of the transgene in the receiving populations (which requires the presence of an appropriate selective pressure, such as an herbicide in the case of herbicide resistance genes) (Gepts & Papa, 2003; Stewart *et al*., 2003; Mallory-Smith & Zapiola, 2008). Ellstrand *et al*. (1999) found that 12 out of 13 important crops have the potential of hybridising with wild relatives, whereby introgression might have occurred for seven of these.

Transgene flow and introgression can have neutral, advantageous or disadvantageous effects on the fitness of the receiving population (Lu, 2008).

5.4.1. Fitness enhancing genes

Transfer of resistance genes, such as those against pests, drought, antibiotics or herbicides, will most likely have a neutral or beneficial effect on the fitness of an organism (*Snow et al*., 2003). If the transgene was to provide a strong selective advantage (e.g. a Bt gene), then a single instance of transgene escape may be adequate for the gene to spread and become fixed (Snow *et al*., 2003). Snow *et al*. (2003) showed that the offspring of a single cross between Bt sunflowers (*Helianthus annuus*) and wild sunflowers were less vulnerable to insects and produced more seeds. The spread of such fitness enhancing traits could result in increased competitiveness, invasiveness and weediness of the population, thus enabling it to outcompete other species, which could have further impacts on biodiversity and the dynamics and balance of the ecosystem (Johnson, 2000). Additionally, transgene hybrids with increased fitness could cause genetic assimilation (i.e. loss of novel genetic identity after generations of hybridisation and backcrossing), which can narrow the gene pool and the available germplasm, and consequently lower the overall biodiversity (Quist, 2007).

5.4.2. Fitness reducing genes

Transfer of fitness reducing genes can put populations at risk or even cause local extinction (Mason *et al*., 2003; Kwit *et al*., 2011). For instance, swarm effects, whereby gene flow reduce the population size or cause extinction of small and/or isolated populations (Ratcliffe, 1973; Ellstrand & Elam, 1993), have been found to occur as a result of interactions between cultivated species and wild relatives. Kiang *et al*. (1979) found a population of Taiwan wild rice (*Oryza rufipogon formosana*) near extinction due to proposed hybridisation and introgression with non-transgenic cultivated varieties (i.e. a swarm effect according to Lu, 2011). That being said, the authors also noted that changes in water management and fertiliser pollution were part of the explanation. Loss of fitness and reduction of population size can also occur due to outbreeding depression, for instance due to fixation of “bad” alleles that exhaust energy/resources and disrupt metabolic processes (Gilbert, 2013). However, Johnson (2000) argues that natural selection would rapidly remove such genes.

5.4.3. Example 1: Effect of fitness enhancing traits – increased invasiveness, competitiveness, and “superweeds”

Transgenes encoding herbicide resistance are proposed to be readily acquired by wild and weedy species via gene flow (Lu, 2008), especially in the case where such genes are dominantly inherited and a sustained selective pressure is present (e.g. repeated exposure to an herbicide) (Gealy *et al*., 2003). Furthermore, studies have indicated increased invasiveness as a result of transfer of advantageous traits such as insect resistance (Samuels, 2013). Consequently, some argue that the upsurge of pesticide resistant weeds and crops plants is caused or exacerbated by the introduction of GM crops (Brown, 2005). For instance, since Monsanto introduced Roundup-tolerant crops in 1996 (Box 5.2), at least 35 species of glyphosate resistant weeds have been identified worldwide, and with significant impacts in Brazil, Australia and Argentina (Gilbert, 2013; Heap, 2016). Alarmingly, as weeds become resistant to glyphosate, farmers may have to revert back to more toxic chemicals (Benbrook, 2012).

Box 5.2. Roundup Ready. Glyphosate is the active ingredient in Roundup Ready, and works by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase which is essential for biosynthesis of aromatic amino acids such as phenylalanine, tryptophan and tyrosine (Industry Task Force on Glyphosate, 2013). Roundup Ready is broad-spectrum and less toxic than many other herbicides on the market, though it has been labelled as a potential carcinogenic by WHO (IARC, 2015).

However, as part of the natural evolution, weeds can – and will – develop resistance to herbicides regardless of whether crops have been genetically modified against it or not. For instance, around 200 weed species have been found to be resistant to ALS herbicides (inhibit the acetolactate synthase enzyme which helps synthesise branch-chained amino acids such as valine and leucine; Whitcomb, 1999), but no crops have been genetically modified to resist ALS (Tranel *et al*., 2016). Furthermore, development of herbicide resistance (e.g. to Roundup Ready) is also explained by bad farm practices, such as relying too heavily on a single herbicide and the lack of crop rotation (Vencill *et al*., 2012).

5.4.4. Example 2: Impact of fitness enhancing and reducing traits on traditional varieties and land races

Africa is home to over 115 indigenous food crops (and certain parts of East Africa are centres of origin and/or diversity for crops such as sorghum, finger & pearl millet, wheat and barley (Johns, 2002; EAPGREN, 2006; Macauley, 2015). Consequently, one of the most voiced concerns associated with biotech crop adoption – which also became evident during the perception surveys – is the potential loss of genetic diversity of traditional crop varieties and landraces. For instance, the Ethiopian government has expressed worries that GMO contamination from neighbouring countries may affect highly culturally valued land races negatively (as cited by Kameri-Mbote, 2012).

Concerns associated with the impact of GM crops on traditional varieties might have been spurred by a much-debated study that claimed to have detected transgenes in land races of maize in a remote area of Mexico (Quist & Chapela, 2001). However, the results showed weak PCR signals, which indicated that only a few kernels were transgenic (i.e. lack of introgression), and the article later became retracted (Metz & Fütterer, 2002).

The emotional, cultural and genetic "wealth" of traditional crops and landraces. It is important to appreciate the strong emotional and cultural ties that farmers and indigenous people may have with certain crop varieties (Gepts & Papa, 2003). Furthermore, traditional varieties and landraces may exhibit gene pools in which genes encoding for agronomic, economic, nutritional and clinically important traits can be found and picked for breeding purposes (Simmonds, 1972). Indeed, plant genetic resources are the raw material upon which the agricultural enterprise – and thus the national economies of the East African countries – relies on. However, once crop diversity is lost, it is not replaceable (EAPGREN, 2006).

Consequently, this genetic "treasury" should be preserved by storage in gene/seed banks, and sampling of this genetic diversity – either for use in conventional or transgenic breeding – should be a prime area of research. Indeed, biotechnology could provide a safeguard of traditional seeds, as opposed to a threat. Such considerations highlight the importance of supporting efforts made by e.g. the Eastern African Plant Genetic Resources Network (EAPGREN), which enhance the ability of members of the Association for Strengthening Agricultural Research in East & Central Africa to conserve and utilise plant genetic resources (ASARECA, 2003).

As a final point, it is also important to recognise that loss of traditional varieties can be caused by several other variables, including socio-economic, economic and agro-ecological/environmental factors (Wale, 2011).

5.5. Development of insecticide resistant pests

Just as with weeds, resistance to insecticides in insect populations will occur as part of the natural evolutionary process (Georghiou & Taylor, 1977). Whether or not cultivation of transgenic crops exacerbate or reduce the selective pressure on insect populations compared to conventional methods is highly debated; one could argue that the selective pressure is greater when using the spray-approach as this affects all the plants in the field (i.e. not just the crop plant as with IR crops). On the other hand, insect resistant biotech crops could accelerate the process as the selective pressure is omnipresent as opposed to conventional cropping whereby the selective pressure can be managed by controlling the amount of insecticide applied and varying damage control agents (Barrows *et al*., 2014). In 2010, the National Research Council reported the presence of resistance in three pest species against toxins found in IR crops (National Research Council, 2010). However, a meta-study on the evolution of Bt resistance in pests showed that most pest populations remained susceptible, while a few populations of the 5/13 major pest species had developed resistance (Tabashnik *et al*., 2009). Still, in 2006, Puerto Rico decided to withdraw IR maize due to growing incidences of pest resistance (Tabashnik *et al*., 2009).

5.6. Resurge of secondary pests

The emergence of secondary pests have been associated with insecticide resistant crops due to (i) reduced application of broad-spectra insecticides; (ii) reduced control by natural enemies (either due to direct effects whereby the natural enemy ingests the insecticide, or indirectly through alterations in the ecosystem such as reduced abundance of prey; Snow *et al*., 2005; Andow *et al*., 2006); and (iii) lower levels of competition by the primary insect targeted by the transgenic crops (Grooet & Dicke, 2002; Catarino *et al*., 2015). However, an upsurge of secondary pests and ecological changes are also relevant for conventional spray methods (Hardin *et al*., 1995; Vitousek *et al*., 1997).

5.7. Other potential effects on non-target organisms

Cultivation of transgenic crops may have indirect impacts on other non-target organisms (e.g. arthropods, herbivores, birds and microorganisms) on various trophic levels, and consequently on the (agro)ecosystem as a whole (Dale *et al*., 2002; Groot & Dicke, 2002; Snow *et al*., 2005; Carpenter, 2011). A study by Nimusiima *et al*. (2015) investigated the effect of BXW-resistant bananas on associated bacterial communities (rhizobacteria and endophytes) under field conditions. The study found no significant difference between transgenic and non-transgenic plants, which indicated that the expression of the transgenes did not affect the non-target microbial community. However, the most infamous study on the effect of transgenic proteins on non-target species was conducted by Losey *et al.* (1999) who investigated the effect of Bt protein on monarch butterflies (*Danaus plexippus*). Larvae of the monarch butterflies that fed on milkweed leaves containing pollen from Bt maize were found to eat less, exhibit a slower growth rate and had higher mortality compared to controls. However, a follow-up study found that the quantities that insects would be exposed to in nature would pose an insignificant threat (Sears *et al*., 2001).

Consequently, when assessing potential non-target effects of transgenic proteins, it is pivotal to evaluate the level of exposure under natural conditions as opposed to the mere toxicity of the protein. Furthermore, it is important to consider the potential positive effects that biotech crops may have on non-target organisms and the ecosystem, for instance due to reduced application of harmful pesticides (Klümper & Qaim, 2014; Bernardes *et al*., 2015).

5.8. Preventative measures of gene flow and development of pesticide resistance

5.8.1. Preventative measures of gene flow

In some cases, such as with most cultivated varieties of banana, the risk of gene flow is small or even negligible due to natural barriers of gene transfer, including ploidy level and sterility (which makes *Musa* spp. highly attractive for genetic engineering) (Vuylsteke, 2000; Lorenzen *et al*., 2010). Furthermore, if the transgene is considered neutral in terms of fitness, which is often the case for transgenes encoding enhanced nutritional composition or quality favourable to the human palate and health, it is likely to have minor environmental impacts (Lu, 2008).

However, for fertile species where pollen/gene flow and subsequent introgression is a possibility, the appropriate precautions and preventative measures should be adopted (Stewart *et al*., 2003). For some "high-risk" crops, this may involve avoiding large-scale genetic modification all together (for instance gene flow from *Sorghum bicolor* to the highly aggressive and global weed *Sorghum halepense*, also known as Johnsongrass) (Stewart *et al*., 2003). For "medium-risk" crops such as maize, alfalfa, sugar beet, wheat, canola and sunflower (Stewart *et al*.,2003), measures to limit transgene escape may include temporal and spatial isolation of the biotech crop, be it physical (e.g. border areas and buffer zones) (Staniland *et al*., 2000; Song *et al*., 2004), chemical (e.g. Schernthaner *et al*., 2003), or molecular (see Box 5.3 for an example) (Daniell, 2002; Mascia & Flavell, 2004; Lemaux, 2009; Kwit *et al*., 2011).

Box 5.3. Gene Use-Restriction Technology (GURT). GURT, otherwise known as Terminator technology, refers to several methods of inhibiting reproduction or inactivating traits in further plantings (Chambers *et al*., 2014). For instance, GURT includes engineering male sterility and production of sterile seeds (Mukherjee & Kumar, 2014), or reducing embryo viability by insertion of a reversible "blocking sequence" which prevents an essential physiological function (Kuvshinov *et al*., 2001). In fact, GURT was originally developed as an alternative mean of Intellectual Property (IP) protection in countries with weak IP frameworks (see Chapter 13 for more information) and was only later on suggested as a way of limiting gene flow between transgenic and conventional crops (Chambers *et al*., 2014). However, GURT remains controversial as it usually requires farmers to buy new seeds every season (which may have implications associated with Farmers' Rights; Chapter 13), thus Monsanto discontinued the use of Terminator technology (Masood, 1998).

5.8.2 Preventative measures against pesticide resistance

Some biotechnological methods can be used to reduce the selective pressure on pests, e.g. by employing tissue-specific or inducible promoters (e.g. Cao *et al*., 2001), and/or by stacking/pyramiding resistance genes (Carrière *et al*., 2010; Gressel *et al*., 2017). However, whether gene stacking delay or speed up the development of resistance has been the topic of some debate (Keim, 2014; Nature Editorial, 2014; Gressel *et al*., 2017). Interestingly, a recent study found that crossing Bt cotton with conventional cotton was a very efficient strategy for counteracting resistance, while still maintaining a high degree of pest suppression and reduced need of applying pesticides (Wan *et al*., 2017). The findings is a further testament of how plants bred via conventional and biotechnological methods can work to complement each other and yield a better result than if either is used alone.

Finally, appropriate use of chemical pesticides (e.g. rotation of pesticides), GAP (e.g. planting of refuges and crop rotation), and best management practices are all important measures for counteracting resistance development (Wang *et al*., 2006; Carrière *et al*., 2010; National Research Council, 2010; FAO, 2012a). However, as touched upon in Chapter 3, most methods require awareness, educational measures and adequate resources to be implemented effectively, all of which may be limited in rural and poor areas. For instance, smallholder farmers seldom employ refuges, while pesticide rotation require continuously buying new chemical inputs, which can be cost and labour-intensive (Sahai & Rehmna, 2003; Sadashivappa & Qaim, 2009). Additionally, it may be hard to encourage certain measures in small-scale farming systems where low yield and productivity is already an issue (for instance, planting of refuges requires one to set aside areas that could otherwise be used to cultivate food or cash crops).

5.9. Concluding remarks

The fact that there have been no documented cases of allergenicity and toxicity in relation to GM food intake is a testament of the efficiency of the current methods of safety testing. Still, transgenics can create unpredicted changes in food, and certain developing countries may require assistance from international and/or regional initiatives to meet the required standard of safety testing. However, more often than not, studies that claim to have found a connection between GM food products and health issues like cancer are largely criticised by the scientific community due to flawed experimental design and/or statistically insignificant or misinterpreted data. Despite this, papers like Séralini *et al*. (2012) have had major influence on regulatory decision-making and perceptions of biotech crops in parts of East Africa.

Concern related to gene flow should not be limited to whether or not the phenomenon is actually occurring and at what rate, but also the type of transgene and its effect on the recipient population, as well as the overall biodiversity and ecosystem performance. However, if the concern over gene spread is valid, is the method of initial production relevant, or does the source of the trait, whether GM or conventional, make a difference? Does the fact that biotech crops may contain genes sourced from different phyla and encode traits that are not normally present in the wild population exacerbate the potential ecological impact? If so, should not conventional crops developed via mutagenesis, whereby novel alleles and traits may arise via point mutations elicited by radiation and mutagenic chemicals (Johnson, 2000; Oladosu *et al*., 2016), also be scrutinised to the same extent?

Furthermore, concerns regarding gene flow, unintended transfer of recombinant DNA and other environmental and ecological effects have to be compared to the natural situation; will the commercialised event produce novel or higher risks, for instance of pesticide and antibiotic resistance, than what is already present under normal circumstances? Will the potential benefits of developing transgenic resistant plants outweigh the potential risk of creating novel and harmful viruses at higher frequencies relative to those occurring during the natural course of evolution? As

Hull *et al*. (2000) so elegantly put it: “The transgenic situation has to be compared with the natural situation, not with a utopian one”.

That being said, there are still many unanswered questions associated with the potential long-term impact of biotech crops on the environment and agro-ecosystem interactions (e.g. emergence of resistant and secondary pests, and other non-target effects) which future studies need to address. Additionally, the major emphasis should be on appropriate management and good agricultural practices, regardless of whether or not the crop is conventional or genetically engineered.

Chapter 6. Case study: Transgenic Bananas Resistant against Banana Xanthomonas Wilt Disease

6.1. Introduction and background information

6.1.1. Description of the problem: Xanthomonas wilt in Musa spp.

Threatened Musa production could affect millions. Bananas and plantains (*Musa* spp.) provide more than 25% of the energy requirement for over 100 million people in Africa, thus represent the fourth most important food crop on the continent (Tripathi *et al*., 2009). Approximately 87% of the global production of bananas derives from small-scale farms, many of which are located in the East African highlands and the Great Lakes region (Tripathi *et al*., 2009; Tripathi *et al*., 2013). In fact, East Africa produces over 20% of the world's output of bananas, making it a major cash crop for tens of millions of farmers (AATF, 2012b).

Alarmingly, production of bananas is affected by several biotic and abiotic factors, including low soil fertility, post-harvest handling, poor practice of husbandry, socio-economic factors (e.g. lack of markets and roads), and pest and diseases (Karugaba & Kimaru, 1999; Ortiz *et al*., 2002). The latter includes the Banana Xanthomonas Wilt (BXW) disease, caused by the bacterium *Xanthomonas campestris* pv. *musacearum*, which is considered the biggest threat to *Musa* production in the Great Lakes region (Tripathi *et al*., 2009).

The first occurrence of Xanthomonas wilt disease was reported on a close relative of banana. The first occurrence of Xanthomonas wilt was reported on a close relative of banana, namely *Ensete ventricosum* – otherwise known as "false banana" – in Ethiopia in 1968 (Yirgou & Bradbury, 1968). *Ensete* is a staple food crop for over 10 million people in Ethiopia, where it is harvested for its starchy pseudostem and corms (Brandt *et al*., 1997). Today, bacterial wilt of *Ensete* has spread to all regions were the plant is grown or occur wild, thus represents a major problem for food security in the country (Brandt *et al*., 1997).

The first outbreak of bacterial wilt on bananas was reported in Uganda in 2001 (Tushemereirwe *et al*., 2004). Uganda is the second largest producer of bananas after India, and the crop is grown by 75% of all farmers (Kalyebara *et al*., 2006; Tripathi *et al*., 2009). The disease rapidly spread to other countries, including the Democratic Republic of Congo, the Republic of Rwanda, Kenya, Tanzania and the Republic of Burundi (Ndungo *et al*., 2006; Reeder *et al.*, 2007; Carter *et al*., 2009). Between 2001 and 2004, Uganda experienced a decrease in yield by 50% and an estimated economic loss of US$ 200 million (Karamura *et al.*, 2008; AATF, 2012b). In Tanzania, sales of bananas decreased by 35%, the price of a banana bunch doubled, and an estimated economic loss of US$ 10.2 million incurred between 2009 and 2011 (Nkuba *et al*., 2015). All in all, the disease costs the East and Central African region over US$500 million per year (Bafana, 2008).

Disease characteristics. Xanthomonas wilt disease is particularly devastating due to its aggressive and rapid nature – it is found on all commonly grown cultivars of banana, where it infects the entire plant in a short amount of time (between two to four weeks depending on the conditions) (Tripathi *et al*., 2013). The development of disease symptoms depends on the route of transmission (see below), the cultivar and the growth stage of the plant, but typically includes yellowing (i.e. chlorosis) and wilting of leaves, bacterial ooze from cut plant organs, rotting of fruits and withering of male buds (Fig. 6.1) (Mwangi & Brandyopadhyay, 2006; Tripathi *et al*., 2009; Tripathi *et al*., 2013).

Routes of transmission and current management of disease. The main routes of transmission occur via infected farm tools and planting material, soil-borne inoculum, wind-driven rain, insect transmission via the male flowers and possibly via birds and bats (Addis *et al*., 2004; Biruma *et al*., 2007; Mwangi *et al*., 2007; Addis *et al*., 2008; Tripathi *et al*., 2009; IRIN, 2012). Consequently, most control measures involve using disease-free suckers for planting material, de-budding, appropriate disposal of infected material, thorough cleaning/sterilisation of farm equipment, and crop rotation (Brandt *et al*., 1997). However, once BXW has infested a field, the rhizosome has to be completely dug out and the field cannot be replanted for over six months due to risk of soil-borne inoculum or, alternatively, has to be placed under a prolonged crop rotation regime (Tripathi *et al*., 2009). Many farmers are apprehensive and/or reluctant to adopt control measures as these can be costly, time-consuming, labour-intensive, and negatively affect the quality of the crop (Bagamba *et al*., 2006; Kagezi *et al*., 2006). Currently, no commercial chemicals or biocontrol agents are available (Tripathi *et al*., 2009).

6.1.2. Agrobacterium-mediated transformation of banana for BXW resistance

Consequently, the development of BXW-resistant cultivars of *Musa spp*. is sorely needed. Conventional breeding methods require resistant donor parents which have yet to be identified in banana germplasm (Tripathi *et al*., 2013). Besides, the process is lengthy and difficult due to ploidy level and sterility (many accessions are triploid), long generation times, low genetic availability, and parthenocarpy (i.e. development of fruit without fertilisation) (Vuylsteke, 2000; Lorenzen *et al*., 2010; Tripathi *et al*., 2013, 2015). In light of this, biotechnological approaches have been considered a more cost-effective solution.

A project collaboration established in 2004/2005 between the International Institute of Tropical Agriculture (IITA) (Kenya), the National Agriculture Research Organisation (NARO) (Uganda) and the African Agricultural Technology Foundation (AATF) has successfully created BXW-resistant lines of banana by insertion of two genes from sweet pepper (*Capsicum annum*) – the hypersensitive response-assisting protein gene (*Hrap)* and a plant ferredoxin-like protein gene (*PflpI)* (Kalyebara *et al*., 2006; Namukwaya *et al*., 2012; Tripathi *et al.*, 2010, 2014a).

HairpinPSS is a type of protein secreted by gram-negative bacteria, including *Xanthomonas campestris*, which aid in the entry into the plant cell (Chen *et al*., 2000). However, hairpinPSS can be detected by receptors in the extracellular matrix of the plant cell wall, upon which a hypersensitive response (HR) is elicited (Chen *et al*., 2000). The HR works by, amongst others, initiating apoptosis of infected plant cells which prevents the further spread of the pathogen (Goodman & Novacky, 1994; Dangl *et al*., 1996), and the local HR is also believed to initiate a systemic acquired resistance (SAR) in the plant (Gaffney *et al*., 1993; Delaney *et al*., 1994; Xie & Chen, 2000). The hypersensitive response-assisting protein (HRAP) is a cell death-associated protein which is present in a range of plants (Ger *et al*., 2002), and works by breaking the hairpin structure into dimers and monomers which cause a more intense HR to be elicited (Chen *et al*., 2000).

Plant ferredoxin-like protein (PFLP) is a ferredoxin-I-type protein that is ubiquitous in the green tissues of many plant species and play an important role in several metabolic pathways, including photosynthesis and synthesis of lipids (Meyer, 2001; Geigenberger *et al*., 2005). Overexpression of the *Pflp* gene has previously proven efficient against bacterial pathogens in transgenic tobacco and rice as a result of increased production of active oxygen species, induction of the HR, and due to its iron depletion activity (Dayakar *et al*., 2003; Huang *et al*., 2004).

Using *Agrobacterium*-mediated transformation, the *Hrap* and the *Pflp* genes under the regulation of the constitutive CaMV35S promoter were inserted into embryogenic cell suspensions (ECSs) and meristematic tissues of four agronomical important cultivars of banana (Tripathi *et al*., 2013). The transgenic embryogenic cells and meristematic explants were allowed to regenerate into rooted plantlets that were later transferred to soil and contained in a screen house. The successful integration of the transgenes was confirmed by PCR analysis and Southern blot, for which the latter indicated a low copy number of one to three copies for most events (Tripathi *et al*., 2013).

In the screen house, the lines that had tested positive for PCR were challenged with an artificial inoculation of the pathogen (Tripathi *et al*., 2013). The method of inoculation resembled transmission via contaminated tools. 50-60% of the lines did not exhibit any disease symptoms 60 days post infection (dpi) and were exposed to another round of infection. This time, 75-85% of the transgenic lines did not develop symptoms 60 dpi (i.e. showed absolute resistance). The resistant lines were further tested using RT-PCR, Northern and Western blots to investigate the successful expression of the transgenes. In contrast, all non-transgenic controls developed disease symptoms, including chlorosis and necrosis (Fig. 6.1) (Tripathi *et al*., 2013)

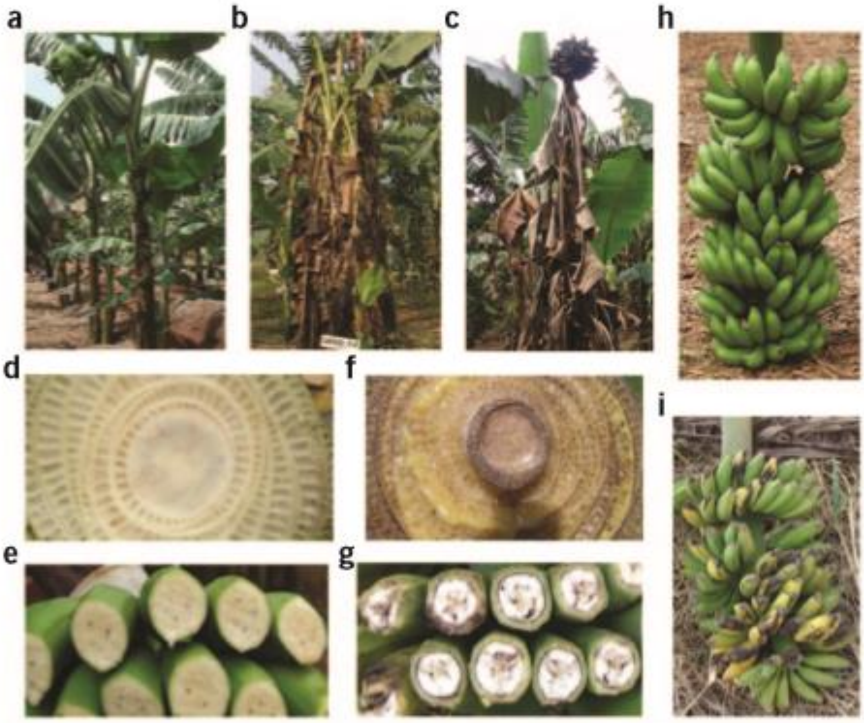


Figure 6.1. Disease symptoms of Banana Xanthomonas Wilt (BXW) in BXW-resistant transgenic and non-transgenic (control) plants of banana. a) Transgenic plants with no symptoms post inoculation. b-c) Control plant exhibiting wilting and rotting of fruit bunch post inoculation. d-e) Transverse section of pseudostem and fruits of transgenic plant with no symptoms, and (f-g) of control plants with bacterial oozing and brown scaring. h) Normal fruit bunch of transgenic plant and (i) bunch of non-transgenic plant exhibiting premature ripening. From: Tripathi *et al*., 2014.

In 2010, the 65 lines exhibiting the highest levels of resistance – of which 40 expressed *Hrap* and 25 expressed *Pflp* – were planted in a confined field trial at the National Agriculture Research Laboratories (NARL) in Uganda (Nordling, 2010). Most of the transgenic lines exhibited normal growth and fruit development which indicated that the transgenes did not negatively influence physiology or yield (Tripathi *et al*., 2014). After reaching the pre-flowering stage, both mother and ratoon plants were exposed to an artificial bacterial inoculation. The transgenic plants displayed significantly higher levels of resistance compared to the non-transgenic controls, and ~20% and ~16% of the *Hrap* and *Pflp* lines exhibited 100% resistance for both mother and ratoon plants, respectively (Tripathi *et al*., 2014).

The lower percentage of lines exhibiting absolute resistance compared to under laboratory conditions was proposed to be a result of environmental factors, variation in gene control, the presence of other pests and pathogens (e.g. *Mycosphaerella fijiensis, Fusarium oxysporum*, weevils and nematodes from neighbouring banana fields), and differences in temporal gene expression due to differences in plant age. In the glasshouse, three months old plants were challenged with an infection compared to at maturity in the field (Tripathi *et al*., 2014).

Using quantitative RT-PCR, the level of transgene transcription in the ratoon plants was shown to vary among lines that displayed different degrees of resistance (i.e. from partial to complete) (Tripathi *et al*., 2014). However, the level of transcription was only positively correlated with pathogen resistance in three out of 14 lines, which indicated that variation in resistance was not a result of transcript accumulation (Tripathi *et al*., 2014).

Future research includes investigating patterns of gene expression during the onset and course of infection, as well as how the transgenes affect transcription of other plant defence genes (Tripathi *et al*., 2014). Additionally, stacked lines carrying both the *Hrap* and *Pflp* genes are currently being tested in a field trial in Kenya (Tripathi, pers. comm.). Furthermore, methods used for transformation and regeneration in Musa *spp*. are being tested in cultivars of *Ensete* in hopes of achieving, amongst others, BXW resistance (Tripathi, pers. comm.).

6.1.3. Somatic embryogenesis

Somatic embryogenesis is a method of micropropagation whereby an embryo develops from a somatic (asexual) cell without any vascular connection with the original tissue, thus bypassing the process of fertilisation and fusion of the gametes (Williams & Maheswaran, 1986; von Arnold *et al*., 2002). It is the totipotent nature of plant cells that enables the somatic cell to be diverted away from its original path of development and acquire the fate of an embryogenic cell (Harada *et al.*, 2010). The switch in the developmental pathway is often induced by some form of stressor or change in the environmental conditions – most commonly by the use of synthetic growth regulators (e.g. auxins such as 2,4-D employed in the protocol for banana) – which induces dedifferentiation of tissues and formation of embryogenic callus (Halperin & Wetherell, 1964; von Arnold *et al*., 2002; Strosse *et al*., 2003).

Somatic embryogenesis can be divided into direct and indirect (Williams & Maheswaran, 1986). During the direct route, the embryo develops from the somatic cell or groups of cells (Williams & Maheswaran, 1986). During indirect embryogenesis, the embryo is formed from an intervening callus, which is the route employed for the establishment of ECSs in banana (Williams &

Maheswaran, 1986). Indirect embryogenesis is often the method of choice as it results in greater genetic diversity due to a higher mutational rate (Slater *et al*., 2008).

Somatic embryogenesis can be used to study the developmental pathways and regulation of embryo growth (von Arnold *et al*., 2002). Additionally, the technique is a much favoured tool for *in vitro* plant regeneration and propagation as it allows for single-cell origin of regenerants, thus circumventing the issue of chimerism (i.e. whereby the plant or a plant part consists of a mixture of two or more genotypically different cells; Encyclopædia Britannica, 1998), as well as automation and large scale propagation in a relatively short amount of time (especially when used in conjunction with bioreactors) (Denchev *et al*., 1992; von Arnold *et al*., 2002). Additionally, somatic embryogenesis can be achieved in more or less any plant species given the appropriate explant, nutrient medium (e.g. type and concentration of plant growth regulators) and environmental conditions (von Arnold *et al*., 2002). Furthermore, embryogenic calli can be maintained for a long time, as well as cryopreserved (e.g. Panis & Thinh, 2001), which allows for creation of gene banks (von Arnold *et al*., 2002).

However, somatic embryogenesis is characterised by certain limitations, including the challenge of inducing somatic embryogenesis, often due to genotypic effects; achieving synchronisation by size when using liquid cultures (e.g. physically by filtering out anything >250 microns); and (iii) somaclonal variation. Such limitations became evident during the practical work of this thesis and will be further investigated in the discussion.

6.1.4. Agrobacterium-mediated transformation

The genus *Agrobacterium* constitutes several species of soil-borne bacteria (including the most commonly known *A. tumefaciens*), whereby some cause diseases such as crown gall, hairy root disease and cane gall disease (Gelvin, 2003). Since it was discovered that *Agrobacterium* has the ability to transfer and integrate bits of its own DNA into the genome of a plant cell (Schell & Van Montagu, 1977), this feature has been exploited by scientists for biotechnological purposes.

Agrobacterium harbours a large (200-800 kbp) tumour-inducing (Ti) plasmid containing a set of virulence (*vir*) genes and a region called the "transferred" T-DNA (Zambryski *et al*., 1983; Schumann, 2006; Christie & Gordon, 2014). The latter is defined by two 25 bp direct repeats, namely the left (L) and right (R) border (Fig. 6.2) (Wang *et al*., 1987). The virulence genes facilitate the transfer and insertion of the T-DNA into the genome of the plant cell via double homologous recombination (i.e. exchange between two similar or identical sequences of DNA) (Gelvin, 2003). In its original state, the T-DNA contains oncogenes and opine-catabolism genes, which aid in infection and cause disease in the plant host (Tzfira & Citovsky, 2006).

The binary vector system and the disarmed Ti-plasmid. For the purpose of genetic transformation, a binary vector system is most commonly used, whereby the T-DNA is contained on one plasmid, while the *vir* genes are located on another (Fig. 6.2) (de Framond *et al*., 1983; Hoekema *et al*., 1983; Bevan, 1984; Lee & Gelvin, 2008). The binary vector system circumvents the problem of having a large and difficult-to-handle plasmid (Lee & Gelvin, 2008). The Ti-plasmid is "disarmed" by replacing the oncogenes and opine-catabolism genes with sequences that facilitates transformation, which usually includes a multiple cloning site (MCS), a selectable marker (for positive selection of transformed plants), promoters, the open reading frame (ORF) of the gene(s) of interest, and terminators (Fig. 6.2) (Lee & Gelvin, 2008).

Additionally, the plasmid contains several other features, including (i) the origin of replication (*ori*) for *Escherichia coli* (enable replication and routine manipulation of the plasmid in *E. coli,* which is the preferred host for genetic manipulation), (ii) an *ori* for *Agrobacterium,* and a (iii) bacterial selectable marker (for positive selection of transformed bacteria) (Lee & Gelvin, 2008; Slater *et al*., 2008). Furthermore, a set of restriction sites allow one to easily cut, move and ligate pieces of DNA from one place to another using restriction enzymes (not shown in Fig. 6.2; see Fig. 6.3 and Fig. 6.4) (Lee & Gelvin, 2008; Slater *et al*., 2008).

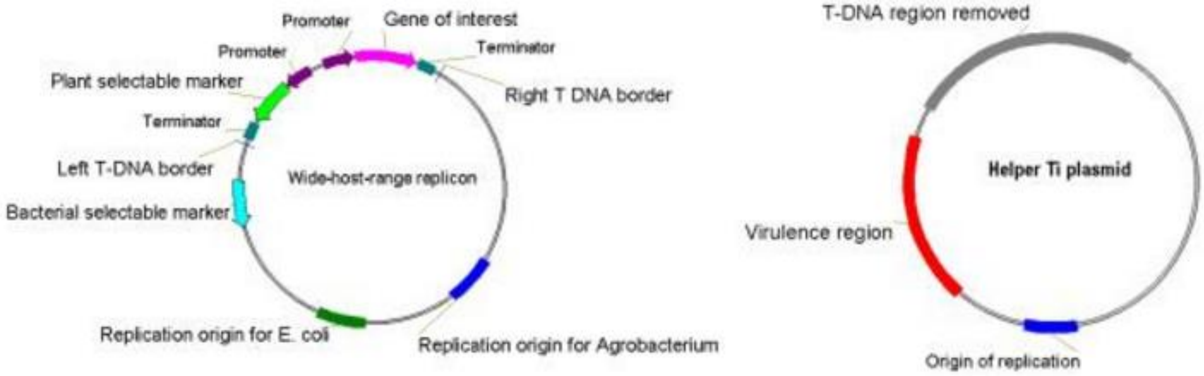


Figure 6.2. The binary vector system for transformation of plant cells. The plasmid to the left contains the expression cassette, while the Helper plasmid (right) exhibits the genes necessary for transfer of the plasmids into the plants cell. Figure from: Roa-Rodriguez & Nottenburg, 2003.

Agrobacterium-mediated transformation. During transformation, a suitable explant (e.g. ECSs) can simply be co-cultivated with transformed and competent *Agrobacterium* (e.g. Clough & Bent, 1998). After co-cultivation, the *Agrobacterium* is killed off using an appropriate antibiotic. Subsequently, the transformed plant cells are selected for – only the cells that have successfully incorporated the construct (with the selectable marker gene) will be able to grow on a medium containing the selective agent. Most often, the selectable marker is an antibiotic or herbicide resistance gene (Ziemienowicz, 2001; Lee & Gelvin, 2008). Ultimately, a whole transformed plant can regenerate from a single cell by transfer onto a shoot and root-inducing medium (i.e. containing the plant growth regulators auxins and cytokinins, respectively) (Skoog & Miller, 1957; Sugimoto *et al*., 2011).

Advantages and demerits of Agrobacterium-mediated transformation. *Agrobacterium*-mediated transformation enables transfer of large pieces of DNA with minimal rearrangements, and can result in a relatively high proportion of transformants exhibiting a low transgene copy number (Lindsey, 1992; Hiei *et al*., 1997; Gheysen *et al*., 1998; Hansen & Wright, 1999; Shibata & Liu, 2000). However, there are drawbacks associated with the method, including (i) low rate of homologous recombination between the T-DNA and the chromosomes of some higher plants (in some cases, recombination can be missing all together) (Gelvin, 2003); (ii) occurrence of gene silencing when multiple copies of a transgene become integrated (e.g. when using multi-copy binary vectors) (Box 6.1); (iii) the possibility of the vector backbone becoming incorporated into the plant's genome, which could potentially disrupt gene regulation and function (Lee & Gelvin, 2008); (iv) the limited host range of *Agrobacterium*; for some time, it was believed that *Agrobacterium* were unable to infect monocots, including Musa *spp*. and the major cereals like rice (D'Hont *et al*., 2012). However, the host range is continuously being expanded (e.g. Hiei *et al*., 1997; Cheng *et al*., 2004; see Nester, 2014 for a more extensive overview).

Box 6.1. Gene silencing. Gene silencing refers to both the absence of expression of an introduced transgene(s) and/or silencing of other endogenous plant genes (known as co-suppression, which assumes a high level of homology) (Stam *et al*., 1997). Both types of silencing can be a result of transcriptional (e.g. due to histone modifications) or post-transcriptional processes (often due to RNAi; Box 3.3.) (Stam *et al*., 1997).

6.1.5. The β-glucuronidase (GUS) and green fluorescent protein (GFP) reporter systems

The use of reporter genes in plant transformation vectors, such as the β-glucuronidase gene (*gusA*) and the green fluorescent protein gene (*gfp*), allows for cheap and rapid identification of transformed cells through visual screening (Ziemienowicz, 2001).

The GUS assay. The β-glucuronidase gene (*uidaA* or *gusA*) is derived from *E. coli* and is particularly suitable for assessing gene activity in most higher plants as they contain only small levels of endogenous GUS activity (however, some plant tissues express GUS-like activity which can interfere with detection) (Jefferson *et al*., 1986; Jefferson, 1987; Guivarc'h *et al*., 1996; Sudan *et al*., 2006). The *gusA* gene is most commonly used in a gene fusion to investigate chimeric gene expression (i.e. whereby the *gusA* ORF is under the control of another gene, such as the CaMV35S promoter), and can provide both quantitative (i.e. whether the gene of interest is being expressed) and qualitative information (i.e. the location of the gene product) (Jefferson, 1987; Gallagher, 1992).

The GUS assay is sensitive, simple and flexible as a range of substrates are available; when obtaining quantitative data, the fluorogenic 4-MUG (4-methylumbelliferyl-β-D-glucuronide) substrate is commonly used (Slater *et al*., 2008). The protein product of *gusA* hydrolyses 4-MUG to 4-MU (4-methylumbelliferone) and the result can be compared to a 4-MUG fluorescence standard curve (Slater *et al*., 2008). Qualitative data is often obtained using X-gluc (5-bromo-4-chloro-3-indolyl glucuronide), which ultimately undergoes oxidative dimerisation to form an insoluble indigo dye (Slater *et al*., 2008). The latter type of GUS assay will be demonstrated in the practical work to verify both transient and stable gene expression.

The GFP assay. The green fluorescent protein (GFP) is a chromophore that originates from the jellyfish *Aequorea victoria* (Shimomura *et al*., 1962). When exposed to ultraviolet (UV) or blue light, the protein will fluoresce in the green part of the visible spectrum (Prasher *et al*., 1992; Cody *et al*., 1993; Chalfie, 1995). GFP is commonly used in plant biology as it allows non-destructive visualisation of transient and stable transformation without the need of adding substrates (contrastingly, the GUS assay is destructive and requires the addition of X-gluc or MUG) (Leffel, 1997; Joshi, 2005). However, molecules such as chlorophyll are known to exhibit autofluorescence which can confound GFP assays (Kautsky & Hirsh, 1931; Strasser *et al*., 2000).

6.2. Lab project

During a four-month long stay at IITA Kenya – which is located in the precinct of the Biosciences Eastern and Central Africa-International Livestock Research Institute (BecA-ILRI) Hub – the protocol for transformation and regeneration in banana and plantain was demonstrated, which included techniques for indirect somatic embryogenesis, *Agrobacterium*-mediated transformation of embryogenic cell suspensions (ECSs) using the reporter genes *gusA* and *gfp*, GUS and GFP assays, molecular analysis (PCR), and tissue culturing.

Two transformation experiments were performed – the first was mostly meant as an initial demonstration using the cultivar 'Cavendish Williams', while the second transformation experiment involved transformation of the cultivars 'Cavendish Williams' and 'Sukali Ndiizi' (for which materials and methods will be reported). However, the cultures of 'Cavendish Williams' of the second experiment had to be discarded, thus the results reported for 'Cavendish Williams' derive from the first transformation experiment.

Due to the time constraints, certain techniques were merely demonstrated, while some of the plant material had been prepared prior to arrival (e.g. the ECSs and cultures of transformed *Agrobacterium*). Furthermore, due to the lengthy process of regenerating whole transgenic plants in banana, the subculturing from the stage of maturation/germination till rooting and the final PCR analysis was carried out by other researchers at IITA (thus, for demonstrational purposes, tissue culturing, stable GUS assays, DNA extraction and PCR analysis was personally performed using other non-transgenic and transgenic plants).

6.2.1. Materials and methods

6.2.1.1. Materials

Plant material. Prior to arrival, immature male flowers and multiple buds were used to induce embryogenic calli of the cultivars 'Sukali Ndiizi' (AAB group) and 'Cavendish Williams' (AAA group), respectively. The embryogenic calli were subsequently used to establish embryogenic cell suspensions (ECSs).

Bacteria. The supervirulent *Agrobacterium tumefaciens* strain EHA105 was employed.

6.2.1.2. Preparing explants for callus induction and establishment of embryogenic cell suspensions (ECSs)

Preparation of multiple buds/scalps (demonstration only). Small buds produced at the base of the shoot tips (from rooted *in vitro* plants; see section 6.2.1.12) were cultured on Multiple Bud Induction Medium (MBI/P4) (Appendices 2, Appendix I.7) and kept in the dark room at 26 ± 2˚C. Sub-culturing was performed every four weeks until aggregates of small buds appeared (after approximately 3-5 months).

Preparation of immature male flowers (demonstration only). For immature male flowers, male inflorescences were collected one month after bunch appearance, whereby the outermost part was removed. The floral apices were surface-sterilised using 70% ethanol (Scharlau) for 2 minutes, followed by washing using sterile distilled water. Washing was repeated thrice. Under sterile conditions, the bracts were removed to reduce the size of the buds to ~2 cm.

Developing embryogenic callus (demonstration only).

Multiple buds/scalps. Using the stereomicroscope (Wild Heerbrugg M8), scalps were excised from meristem cultures and transferred to Callus Induction Medium (CIM1/ZZ) (Appendices 2, Appendix I.8). The cultures were kept in the dark at 26 ± 2˚C until friable embryogenic callus started to develop after ~4-6 months (without refreshing medium).

Immature male flowers. Using the stereomicroscope (Wild Heerbrugg M8), 6-9 immature flowers from position 16 to 8 (Strosse *et al.,* 2003) were isolated and transferred to a 90-mm petri dish containing Callus Induction Medium (CIM2/MA1) (Appendices 2, Appendix I.13). The cultures were kept in the dark at 26 ± 2˚C for approximately 4-7 months without refreshing the medium, and checked every two weeks for the development of callus.

Establishing Embryogenic Cell Suspensions (ECSs) (demonstration only). Creamish yellow, friable embryogenic calli containing translucent, early-stage pro-embryos were identified using the stereomicroscope (Wild Heerbrugg M8, plan 1x). Using two needle tips attached to syringes (BD), the embryogenic callus was picked and added to a 25 ml conical flask (Pyrex) containing 5-6 ml liquid Callus Induction Medium (i.e. MA2 in the case of immature male flowers and ZZ medium in the case of multiple buds; Appendices 2, Appendix I.14 and I.8, respectively). Between the first and third week after initial transfer, the medium was gradually increased to 10 ml. At the start of the fourth week, fine granular cells were transferred to a new 25 ml conical flask. After two months, the fine cells were transferred to a 250 ml conical flasks containing 30-40 ml of MA2/ZZ.

6.2.1.3. Refreshing medium of embryogenic cell suspensions (ECSs)

Under sterile conditions, fresh MA2/ZZ medium was added to the 250 ml conical flask containing the ECSs (adding up to ~150 ml) and swivelled briefly to mix. ~25 ml of fresh MA2/ZZ medium was added to autoclaved and completely dry 250 ml conical flasks. Using a disposable pipette (Thermo Fisher Scientific, Fisherbrand^{TM}), 20-25 ml of old medium containing the fine granular cells were transferred to the new flask, avoiding the larger aggregates of cells. The pipette was changed between each culture. An alternative and cruder method was to directly discard ~80% of the old medium, thus leaving behind ~20% (containing most of the embryogenic cells). Subsequently, fresh medium was added up to about ~25 ml. The conical flasks were capped using aluminium foil, cling-filmed and restored back to the dark room at 26 ± 2˚C and 95 rpm agitation. The medium was refreshed every 15 days or earlier depending on the growth rate. Before transformation, the medium was refreshed 5 days prior.

6.2.1.4. Preparing *Agrobacterium* for transformation

Agrobacterium strain and plasmid construct.

For the transformation experiments, two binary vectors were employed:

(i) pCAMBIA2301 containing the neomycin phosphotransferase (*nptII*) gene as a selectable marker (under the control of the CaMV35S promoter) and the β-glucuronidase (*gusA*) gene (under the control of the CaMV35S promoter and the nopaline synthase (*Nos*) terminator) (NCBI Genbank, AF234316.1) (Fig. 6.3). The size of the construct was 11633 bp, with the incorporated *gusA* gene being 2053 bp.

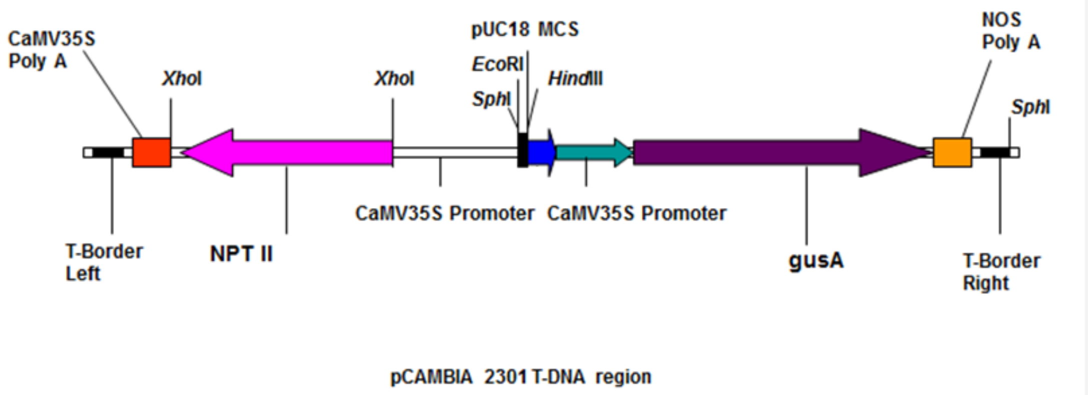


Figure 6.3. pCAMBIA2301 construct used for transformation of the banana cultivars 'Cavendish Williams' and 'Sukali Ndiizi' for the expression of the reporter gene β-glucuronidase (*gusA*) .

(ii) pCAMBIA2300-gfp containing the neomycin phosphotransferase (*nptII*) gene as a selectable marker (under the control of CaMV35S promoter) and the green fluorescent protein (*gfp*) gene (under the control of the CaMV35S promoter and the nopaline synthase (*Nos*) terminator) (Fig. 6.4). The *guA* gene was replaced by the *gfp* gene (714 bp) in pCAMBIA2301, and the construct was named pCAMPIA2300-gfp (10294 bp).

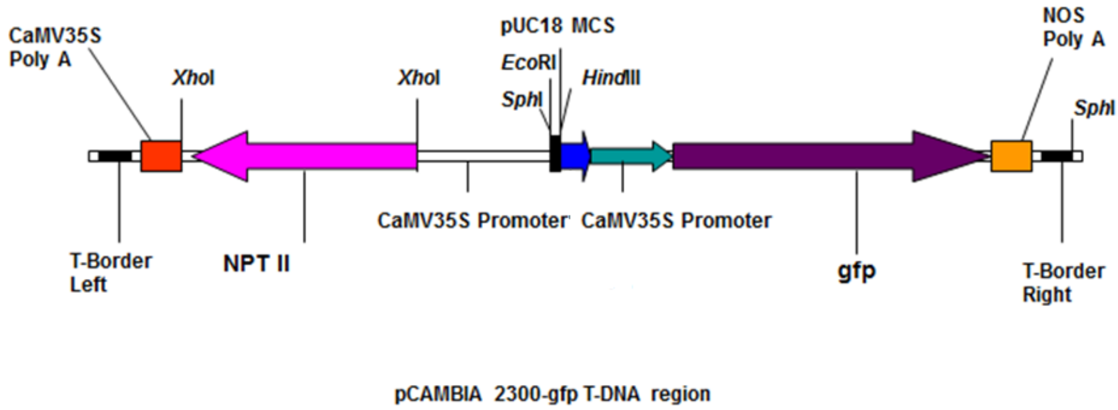


Figure 6.4. pCAMBIA2300-gfp construct used for transformation of the banana cultivars 'Cavendish Williams' and 'Sukali Ndiizi' for the expression of the reporter gene green fluroscent protein (*gfp*).

The *A. tumefaciens* strain EHA105 was transformed using electroporation prior to arrival (Hood *et al*., 1992). The transformed EHA105 were kept on solid LB medium (0.8% agar) (Appendices 2, Appendix I.17) supplemented with 50 mg/l kanamycin and 50 mg/l rifampicin. For long-term storage, the *Agrobacterium* was kept in a glycerol stock at -80̊ C.

Streaking plates of Agrobacterium and picking single colonies. For streaking, two cultures containing pre-prepared EHA105 transformed with pCAMBIA2300-gfp (from now on referred to as PC2300-gfp) and pCAMBIA2301 (from now on referred to as PC2301) were used. A sterile loop was used to streak each respective bacterial culture onto separate plates containing solid LB supplemented with 50 mg/l kanamycin and 25 mg/l rifampicin. The plates were clingfilmed and incubated at 28˚C for 24-48 hours, after which bacterial growth and the presence of single colonies were checked.

In the fume hood, 30 ml of LB medium was added to two 100 ml conical flasks. Subsequently, 30 µl of kanamycin and 30 µl of rifampicin were added by pipetting. Using a sterile loop, a single colony from the streaked EHA105 transformed with PC2301 was added to the conical flask. The process was repeated for the plate containing EHA105 transformed with PC2300-gfp. The cultures were incubated overnight at 28˚C on a rotary shaker (200 rpm) (New Brunswick Scientific, 126 Lab Incubator shaker series).

Refreshing media of Agrobacterium cultures. Under sterile conditions, 50 ml of LB was measured using a falcon tube and added to a 250 ml conical flask, after which 50 µl of kanamycin and 50 µl of rifampicin was added by pipetting. The flask was swivelled briefly to mix. Subsequently, 1 ml of the *Agrobacterium* culture EHA105 PC2301 was added by pipetting. The flask was swivelled lightly, sealed and incubated at 28˚ C on a rotary shaker (200 rpm). The process was repeated for EHA105 PC2300-gfp.

Plasmid extraction and agarose gel analysis to verify presence of constructs in cultures of Agrobacterium. The plasmid DNA was extracted using the QIAprep® Spin Miniprep Kit (Qiagen) (Appendices 2, Appendix A). A total of four samples were prepared – two containing DNA extracted from EHA105 PC2301 (labelled “GUS1” and “GUS2”) and two containing DNA extracted from EHA PC2300-gfp (labelled “GFP1” and “GFP2”). A nanodrop reading was performed for each sample by applying 1-2 µl of DNA to the apparatus and using the TE buffer as a blank.

For the gel electrophoresis, a total of 8 wells were loaded – one well containing a 1 kb+ ladder, two wells containing plasmid DNA from “GUS1”, two wells containing plasmid DNA from “GUS2”, two wells containing plasmid DNA from “GFP1”, and one well containing plasmid DNA from “GFP2”. Firstly, 7 µl of diluted ladder was loaded into the first well. Subsequently, a 2 µl of loading dye was mixed with 5 µl of each sample by pipetting, before loading the entire volume into each respective well.

The plasmid DNA was separated by electrophoresis in a 1% agarose gel (5xTBE buffer and 2.5 µl GelRed) (Appendices 2, Appendix B). Electrophoresis was run for 60 minutes at 100 V, after which the gel was observed using the UV transluminator INGENIUS 3 (Syngene) and the InGenius 3 software.

6.2.1.5. Co-cultivation and transformation of ‘Cavendish Williams’ and ‘Sukali Ndiizi’

Preparing the Agrobacterium cultures. Before commencing, the OD_{600} of the overnight *Agrobacterium* cultures was measured (OD_{600} = >0.8), whereby LB supplemented with kanamycin and rifampicin was used as a blank. 25 ml of each bacterial culture was added to one falcon tube each, giving a total of four samples (i.e. two containing EHA105 PC2300-gfp and two containing EHA105 PC2301). The samples were spun down for 15 minutes at 4000 rpm at room temperature (Eppendorf centrifuge 5415R), after which the supernatants were discarded. The pellets were re-suspended in 25 ml of Bacterial Resuspension Medium (BRM) (Appendices 2, Appendix I.16) and incubated for 2-3 hours at 70 rpm at room temperature. Subsequently, OD_{600} was checked (using BRM as a blank) and adjusted to 0.5-0.7 by adding BRM if necessary (note: OD/desired volume x volume of culture = final volume required OD).

Embryogenic cell preparation. 250 ml conical flasks containing ~6 and ~14 months old ECSs of the varieties 'Sukali Ndiizi' and 'Cavendish Williams', respectively, were transferred to the fume hood. The ECSs were poured into 50 ml falcon tubes and allowed to settle, after which the excess medium was discarded. The ECSs were heat shocked by adding 10 ml of pre-warmed (45-48˚C) ZZ/MA2 liquid medium to each falcon tube for 5 minutes, after which the excess medium was decanted (leaving behind ~5 ml of ECS).

Co-cultivation of ECSs with Agrobacterium. 10 ml of pre-induced *Agrobacterium* culture was added to each falcon tube containing the ECS. A total of 6 treatment types were established – (i) one sample containing 'Cavendish Williams' transformed with EHA105 PC2301; (ii) one sample containing 'Cavendish Williams' transformed with EHA105 PC2300-gfp; (iii) two samples of 'Sukali Ndiiizi' transformed with EHA105 PC2301; (iv) one sample containing 'Sukali Ndiiizi' transformed with EHA105 PC2300-gfp; and (v) one sample containing a non-transformed (negative) control of 'Sukali Ndiizi'.

110 µl (0.2%) of detergent pluronic F68 (from a 2% stock) (Sigma Aldrich) was added to all tubes expect control, after which the tubes were centrifuged (Eppendorf, 5810R) for 5 minutes at 900 rpm at room temperature. Centrifugation was repeated twice. Subsequently, the co-cultivated cells were incubated for 30-60 minutes with gentle shaking (30-35 rpm) (Stuart, mini see-saw rocker) at room temperature.

In the fume hood, the cells were allowed to settle. Using sterile forceps, small squares of autoclaved nylon mesh paper were transferred onto a pile of autoclaved paper towels. Using cut 1 ml pipette tips (Thermo Scientific), the co-cultivated cells were pipetted onto the mesh and allowed to dry before being transferred to a 45-mm petri dish (Thermo Scientific) containing Bacterial Co-Culture Medium (BCCM) (Appendices 2, Appendix I.15). The pile of paper towels were changed between each new treatment type (i.e. type of cultivar and construct), and forceps were sterilised using a bead steriliser (Lab Associates). The sealed plates were cling-filmed and co-cultured for 3 days in the dark at 26 ± 2˚C.

6.2.1.6. Transient and stable histochemical GUS assay

The histochemical GUS assay for transient gene expression was carried out three days after co-cultivation. In a falcon tube, 10 ml of GUS mastermix was created (Appendices 2, Appendix C). In the fume hood, the nylon mesh containing the co-cultivated embryogenic cells was transferred into an empty 45-mm petri dish. 2-3 ml of mastermix was added, making sure to completely submerge the cells. The protocol was performed using two samples of 'Sukali Ndiizi' and one sample of 'Cavendish Williams'. The samples were incubated overnight at 37˚C and observed the following day using the Nikon SMZ1500 microscope and the NOS-Elements F 3.2 software.

The stable histochemical GUS assay was performed using whole putative transgenic plantlets of 'Sukali Ndiizi'. In the fume hood, the roots and leaves were removed using forceps and a scalpel. The explants were cut into smaller pieces and transferred to the bottom of a centrifuge tube (Eppendorf), after which 2-3 ml of mastermix was added and vacuum infiltration was applied (the process of sonication was also demonstrated, but not performed) (Apendices 2, Appendix D). During the demonstration, a positive control using explants of *Nicotiana tabacum* transformed with the same PC2301 construct was included (a negative control using explants from a non-transformed plant was not included). The samples were incubated overnight at 37˚C, after which they were washed using ~2 ml ethanol before observation.

6.2.1.7. Green fluorescent protein (GFP) assay

Embryogenic cells transformed with *gfp* and controls were checked at the 4th, 83rd and 87th day after transformation for 'Sukali Ndiizi', and at the 16th, 93rd and 97th day for 'Cavendish Williams', using the Nikon SMZ1500 microscope and the NOS-Elements F 3.2 software.

6.2.1.8. Washing of co-cultivated embryogenic cells for removal of *Agrobacterium*

Three days after co-cultivation, the embryogenic cells were washed using ZZ/MA2 supplemented with antibiotics (1 ml of cefotaxime (300 mg/l) was pipetted into 1 L stock of ZZ/MA2-media). The solution was mixed gently, after which 15 ml were added to 50 ml Falcon tubes. Using forceps (Duchefa), the nylon mesh containing the embryogenic cells was dipped into the Falcon tube until the cells came loose in the solution. All the samples containing ECSs of the same variety (i.e. 'Sukali Ndiizi' or 'Cavendish Williams') and transformed with the same construct (i.e. PC2300-gfp or PC2301) were added to the same Falcon tube. The cells were allowed to settle before slowly discarding the excess medium. Washing was repeated trice. After the third wash, a small amount of ZZ/MA2 was left behind in the Falcon tube together with the embryogenic cells.

Larger-cut pieces of nylon mesh were placed onto a pile of sterile paper towels using forceps. Using cut pipette tips, the washed and Agro-infected ECSs were pipetted onto one or several pieces of mesh (depending on the amount of ECS in each tube), while making sure to leave out larger aggregates of cells. The mesh was allowed to dry before being transferred into a 90-mm petri dish (Citotest labware) containing Embryo Development Medium (EDM/MA3) supplemented with 300 mg/l cefotaxime (Appendices 2, Appendix I.9). The protocol was repeated for each respective cultivar and type of construct, and the pile of paper towels was changed between each treatment type. A total of 8 plates were prepared: (i) three plates of 'Sukali Ndiizi' transformed with *gfp*; (ii) two plates 'Sukali Ndiizi' transformed with *gusA*; (iii) one plate of 'Cavendish Williams' transformed with *gfp*; (iv) one plate of 'Cavendish Williams' transformed with *gusA*; and (v) one 'Sukali Ndiizi' control plate (note that the control was not washed as described above and was cultured on MA3 without selection).

The plates were clingfilmed, wrapped in foil and stored in the dark room at 26 ± 2˚C.

6.2.1.9. Re-freshing medium and transfer to *Agrobacterium* and plant selective medium

After seven days, the nylon mesh containing the agro-infected embryogenic cells were transferred using forceps into 90-mm petri dishes containing MA3 Medium supplemented with 300 mg/l cefotaxime and 100 mg/l kanamycin. The control was transferred onto MA3 without selection. Plates were kept in the dark room at 26± 2˚C and the medium was refreshed every 14-15 days.

6.2.1.10. Further selection and regeneration

Once small and white embryos started to appear (after approximately 1 ½ -2 months), a fine-bladed scalpel (Duchefa) was used to pick and transfer the embryos into 90-mm petri dishes containing Embryo Maturation Medium (EMM/RD1) (Appendices 2, Appendix I.10) supplemented with cefotaxime (300 mg/l) and kanamycin (100 mg/l). Plates were kept in the dark at 26± 2˚C. The embryogenic cells contained on MA3 were retained for further growth (i.e. in the dark room at 26 ± 2˚C) and picking of single embryos for another 1-2 months.

In the case where embryos had not matured after one month on RD1, subsequent sub-culturing on RD1 (with/without selection) or on RD2 (1 mg/ml BAP)(Appendices 2, Appendix I.12) was carried out (plates were stored in the dark room at 26 ± 2˚C). After 1-2 months on RD1 or RD2, mature embryos were picked as described above and transferred onto Germination Medium (GM/MA4) (1 mg/ml BAP) for shoot germination (Appendices 2, Appendix I.11). The plates were stored in the dark room at 26 ± 2˚C and the medium was refreshed every 14-15 days.

When white shoots started to appear, the shoots were transferred to Proliferation Medium (PM) (2.5 mg/l BAP) without cefotaxime for shoot development (Appendices 2, Appendix I.4 and I.5). The regenerated shoots were transferred to light conditions (26± 2°C, 16 h photoperiod, photosynthetic photon fluence rate 50 µmol $m^{-2} s^{-1}$) upon which they turned green (after approximately 1-2 weeks). After about one month, shoots containing 3-4 leaves were transferred to Rooting Medium (RM) (IBA (1 mg/ml IBA) (Appendices 2, Appendix I.6) without cefotaxime for 2-4 weeks. Subsequently, rooted plantlets were transferred into sterile soil in pots for further molecular analysis and bioassays (i.e. PCR analysis for the purpose of this thesis).

6.2.1.11. DNA extraction and Polymerase Chain Reaction (PCR) analysis of rooted plantlets

Extraction of genomic DNA. Genomic DNA was extracted from fresh leaves of transgenic plants of 'Sukali Ndiizi' (26 weeks old) using the DNeasy® Plant Mini Kit (Qiagen) (Appendices 2, Appendix E). Using a surgical blade, a piece of the outermost part of the top-most leaf of the banana plant was cut. The leaf tissue was wrapped in aluminium foil, labelled with the variety name and the transgenic line number, and stored in liquid nitrogen. The procedure was repeated for all transgenic lines investigated, including a negative control (i.e. non-transformed plant). The samples were disrupted by transferring the leaf into a mortar containing liquid nitrogen. Using the pestle, the leaf was ground into a fine powder and stored in a centrifuge tube in liquid nitrogen. The genomic DNA was extracted using the protocol described in Appendices 2, Appendix E.

Polymerase chain reaction (PCR). The PCR reaction mix was prepared as described in Table 6.1 (all reagents from Qiagen). Please refer to Appendices 2, Appendix F for a more detailed description of the protocol.

Table 6.1. Components of the Polymerase Chain Reaction (PCR) mix (25 µl reaction).

Components	**Concentration (µl)**
10X PCR Buffer	2.5
$MgCl_2$	0.5
dNTPs	0.5
ORF-Forward Primer	1.0
ORF-Reverse Primer	1.0
Taq Polymerase	0.2
Nuclease-free H_2O	14.3
gDNA template	5.0
Total	25

PCR was performed using *gusA*-specific primers [forward primer 5'- TTTAACTATGCCGGGATCCATCGC -3' and reverse primer 5'- CCAGTCGAGCATCTCTTCAGCGTA 3'] (Nyaboga *et al*., 2014) and *gfp*-specific primers [forward primer 5'- TTCTGTCAGTGGAGAGGGTG -3'and reverse primer 5'- CTGGTAAAAGGACAGGGCCA-3'] (as provided by Dr. Leena Tripathi, IITA). The thermocycling conditions for the PCR are described in Table 6.2. A thermocycler from Applied Biosystems were employed.

Table 6.2. Thermocycling conditions for the Polymerase Chain Reaction (PCR).

Step	Temperature	Duration
Initial denaturation	95˚C	5 min
Denaturation	94˚C	30 sec
Annealing	60˚C	1 minute
Extension	72˚C	1 min
Final extension	72˚C	7 min
	Step 3 and 4 repeated for 35 cycles.	
	4˚C	~

For the PCR analysis, a 1 kb+ ladder, a positive control containing plasmid DNA, a negative control containing gDNA from a non-transgenic plant ("wildtype", W), and a negative control with nothing added ("blank", B), was loaded in addition to the samples. The PCR products were separated by electrophoresis in a 1.5% agarose gel (Duchefa) (0.5xTBE buffer and 2.5 µl GelRed) at 100V for 60 minutes. Subsequently, the gel was visualised using the UV transluminator InGenius 3 (Syngene) and the InGenius 3 software.

6.2.1.12. Tissue culturing for maintenance of plantlets and production of multiple buds/scalps

Firstly, the food jars containing non-transgenic rooted plantlets were checked for contamination; in the case of fungal contamination, the cultures were discarded. If there was bacterial contamination present, cefotaxime or other anti-bacterial agents were used to clean the cultures. Subsequently, the plantlets were transferred from the food jar onto a sterile paper towel using forceps. The roots, shoot tips, outer leaves and any sign browning (phenols) were removed using a scalpel to obtain a clean shoot. Where applicable, "injuring" was performed by cutting a cross on the top of the shoot using a scalpel. 3-5 shoots were placed with the basal side down into a new food jar containing Proliferation Medium. The equipment was sterilised using a bead steriliser and the paper towels were changed between each food jar.

6.2.2. Results

6.2.2.1. Nanodrop readings

The nanodrop reading for the nucleic acid concentration and quality performed for the first transformation experiment showed values within the optimal range, except for sample 4 ("GUS2") (Table 6.3).

Table 6.3. Nanodrop reading for plasmid constructs pCAMBIA2300-gfp ("GFP1" and "GFP2") and pCAMBIA2301 ("GUS1" and "GUS2") for the transformation of the banana cultivar 'Cavendish Williams' (first transformation experiment).

Sample	Nucleic acid concentration (ng/µl)	260/280[1]	260/230[2]
1: "GFP1"	122.9	1.91	2.18
2: "GFP2"	64.0	1.90	2.07
3: "GUS1"	163.5	1.84	2.13
4: "GUS2"	36.8*	1.80	1.99

[1] Measure of nucleic acid purity (Thermo Scientific, 2009).
[2] Secondary measure of nucleic acid purity (Thermo Scientific, 2009).
Note: Optimal level for nucleic acid concentration is >50 µg per µl; optimal level for 260/280 is ~1.8 for DNA and ~2.0 for RNA; optimal level for 260/230 is usually between 2.0 and 2.2. For PCR, lower concentrations and quality is acceptable (Thermo Scientific, 2009).
*Indicate values below optimal level.

The nanodrop reading performed for the second transformation experiment indicated low nucleic acid concentrations, while some samples exhibited presence of contamination, especially sample 2 ("GFP2") (Table 6.4).

Table 6.4. Nanodrop reading for plasmid constructs pCAMBIA2300-gfp ("GFP1" and "GFP2") and pCAMBIA2301 ("GUS1" and "GUS2") for the transformation of the banana cultivars 'Cavendish Williams' and 'Sukali Ndiizi' (second transformation experiment).

Sample	Nucleic acid concentration (ng/µl)	260/280[1]	260/230[2]
1: "GFP1"	19.3*	1.97	1.74*
2: "GFP2"	7.6*	1.72*	1.69*
3: "GUS1"	13.6*	2.03	1.75*
4: "GUS2"	21.7*	1.81	1.87

[1] Measure of nucleic acid purity (Thermo Scientific, 2009).
[2] Secondary measure of nucleic acid purity (Thermo Scientific, 2009).
Note: Optimal level for nucleic acid concentration is >50 µg per µl; optimal level for 260/280 is ~1.8 for DNA and ~2.0 for RNA; optimal level for 260/230 is usually between 2.0 and 2.2. For PCR, lower concentrations and quality is acceptable (Thermo Scientific, 2009).
*Indicate values below optimal level.

6.2.2.2. Agarose gel analysis: Verifying the presence of the plasmid constructs in cultures of *Agrobacterium*

Verifying the presence of the plasmid constructs pCAMBIA2301 and pCAMBIA2300-gfp in Agrobacterium cultures used for transformation of 'Cavendish Williams' (first transformation experiment)

Extraction of plasmid DNA from putatively transformed cultures of *Agrobacterium* EHA105 and subsequent analysis by agarose gel electrophoresis demonstrated bands at approximately 10000-12000 bp, which is consistent with the size of pCAMBIA2301 (~11633 bp) (i.e. "GUS1" and "GUS2") and pCAMBIA2300-gfp (~10294bp) (i.e. "GFP1" and "GFP2") (Fig. 6.5).

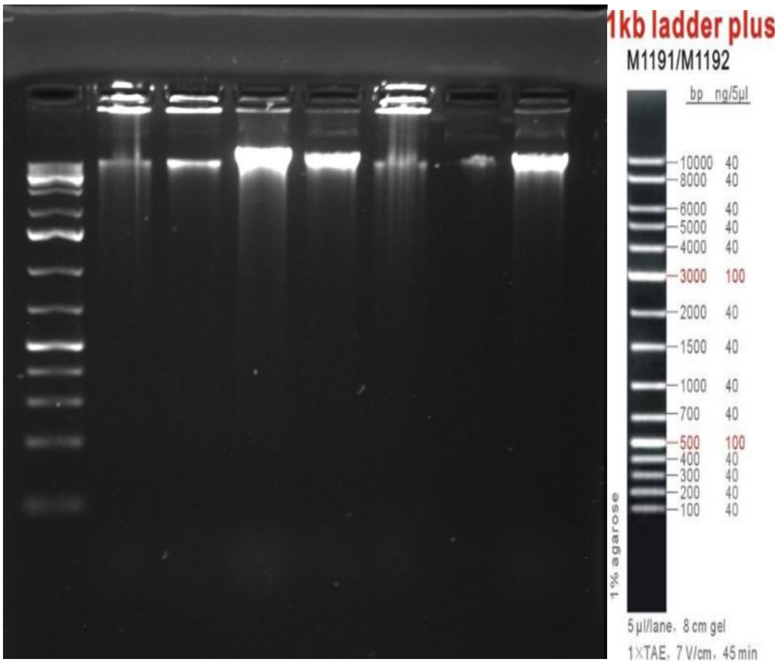


Figure 6.5. Agarose gel analysis of plasmid extraction from *Agrobacterium* EHA105 cultures harbouring the constructs pCAMBIA2301 ("GUS1" and "GUS2") and pCAMBIA2300-gfp ("GFP1" and "GFP2"), respectively. From left to right: 1 Kb ladder (see insert right), "GUS1", "GUS2", "GFP1", "GFP2", "GUS1", "GFP1", "GFP2". Bands are apparent at approximately 10000-12000 bp, which is consistent with the size of pCAMBIA2301 (~11633 bp) and pCAMBIA2300-gfp (~10294 bp).

Verifying the presence of the plasmid constructs pCAMBIA2301 and pCAMBIA2300-gfp in Agrobacterium cultures used for transformation of 'Cavendish Williams' and 'Sukali Ndiizi' (second transformation experiment)

Extraction of plasmid DNA from putatively transformed cultures of *Agrobacterium* EHA105 and subsequent analysis by agarose gel electrophoresis showed bands at approximately 10000-12000 bp, which is consistent with the size of PC2301 (~11633 bp) (i.e. "GUS1" and "GUS2") and PC2300-gfp (~10294 bp) (i.e. "GFP1" and "GFP2") (Fig. 6.6).

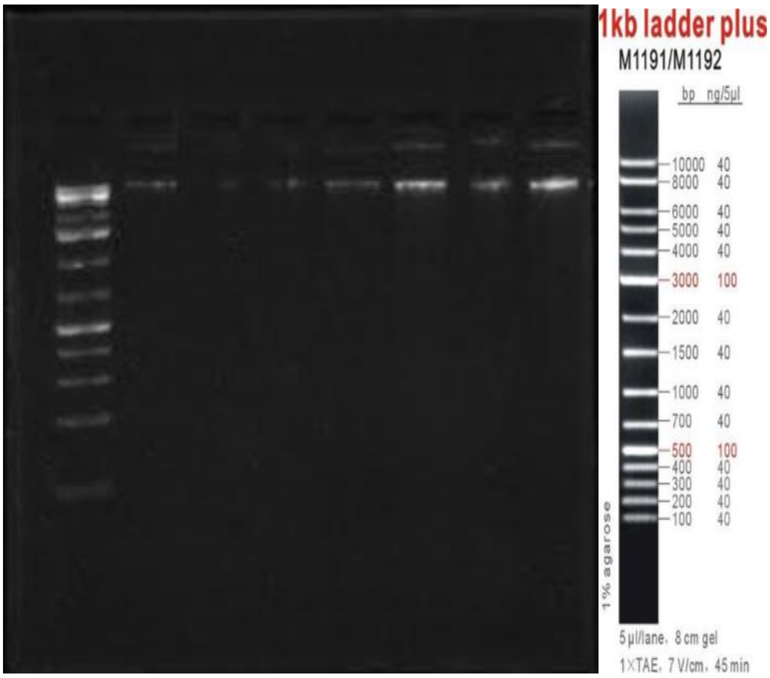


Figure 6.6. Agarose gel analysis of plasmid extraction from *Agrobacterium* EHA105 cultures harbouring the constructs pCAMBIA2301 ("GUS1" and "GUS2") and pCAMBIA2300-gfp ("GFP1" and "GFP2"), respectively. From left to right: 1 Kb+ ladder (see insert right), "GUS1", "GUS2", "GFP1", "GFP2", "GUS1", "GUS2", "GFP1". Bands are apparent at approximately 10000-12000 bp, which is consistent with the size of pCAMBIA2301 (~11633 bp) and pCAMBIA2300-gfp (~10294 bp).

6.2.2.3. Development of embryogenic cells

For more images of embryogenic cell development and picking and transfer of single embryos, please refer to Appendices 2, Appendix G and H, respectively.

'Sukali Ndiizi'

Embryos started to appear in cultures of 'Sukali Ndiizi' transformed with gfp and *gusA,* as well as in controls (data not shown), approximately 25 days after transformation (Fig. 6.7a and Fig. 6.8a, respectively). Embryos were ready for picking and transfer to RD1 after one-and-a-half to two months on MA3 with/without selection (Fig. 6.7b+c and Fig. 6.8b+c). Embryos started to show signs of germination after approximately one month on RD1 with/without selection (i.e. shortly before leaving IITA in mid-December of 2016) (Fig. 6.7d and Fig. 6.8d+e).

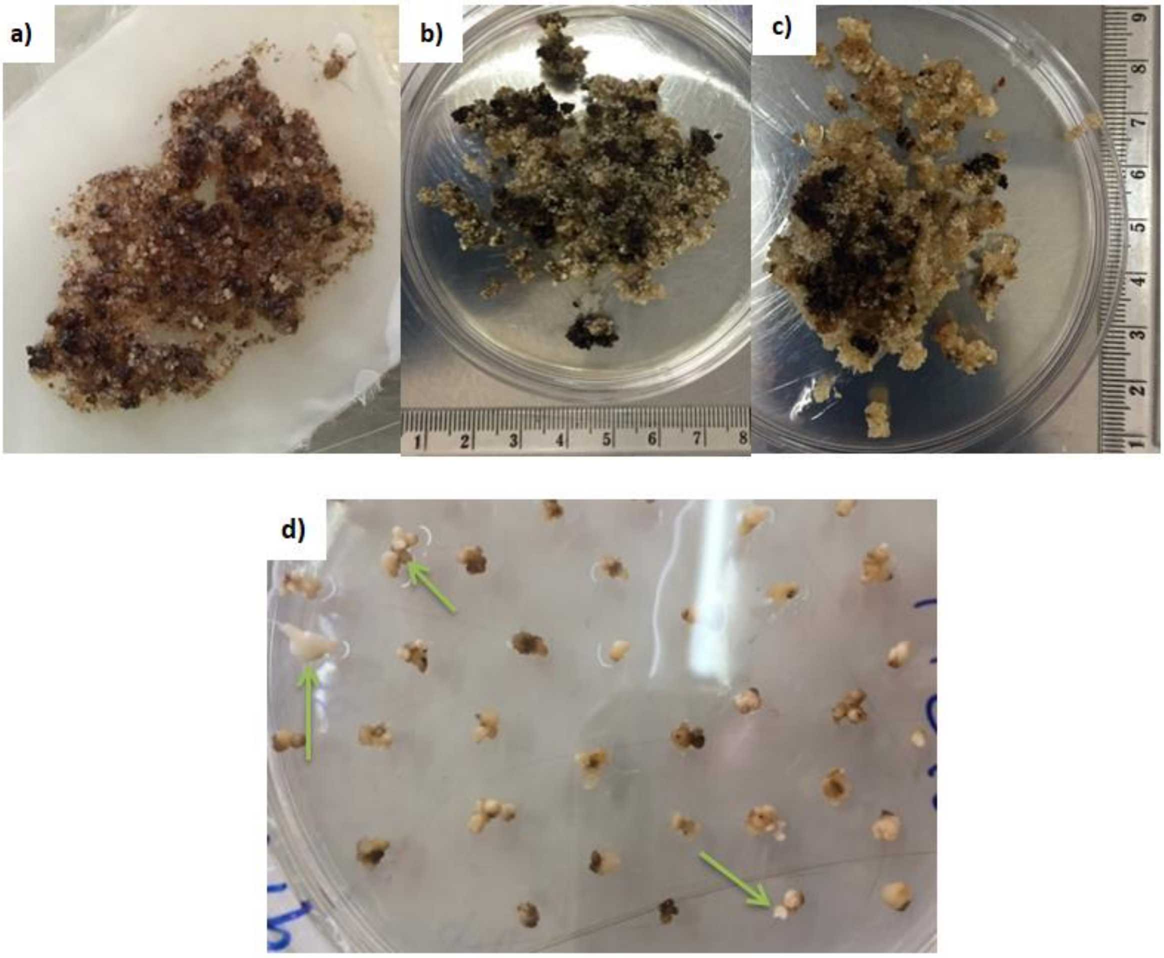


Figure 6.7. a) Embryogenic cells of the banana cultivar 'Sukali Ndiizi' transformed with green fluorescent protein (*gfp*) cultivated on Embryo Development Medium (MA3) with selection 25 days after transformation. White embryos have started to appear. **b) Embryogenic cells of 'Sukali Ndiizi' transformed with *gfp* cultivated on MA3 with selection 65 days after transformation.** Embryos were picked and transferred to Embryo Maturation Medium (RD1) with selection. **c) Non-transformed embryogenic cells of 'Sukali Ndiizi' (negative control) cultivated on MA3 without selection 65 days after initiation of the transformation experiment.** Embryos were picked and transferred to RD1 without selection. **d) Germinating embryos (indicated by arrows) of 'Sukali Ndiizi' transformed with *gfp* after approximately one month on RD1 with selection.** Embryos were transferred to Germination Medium (MA4) with selection.

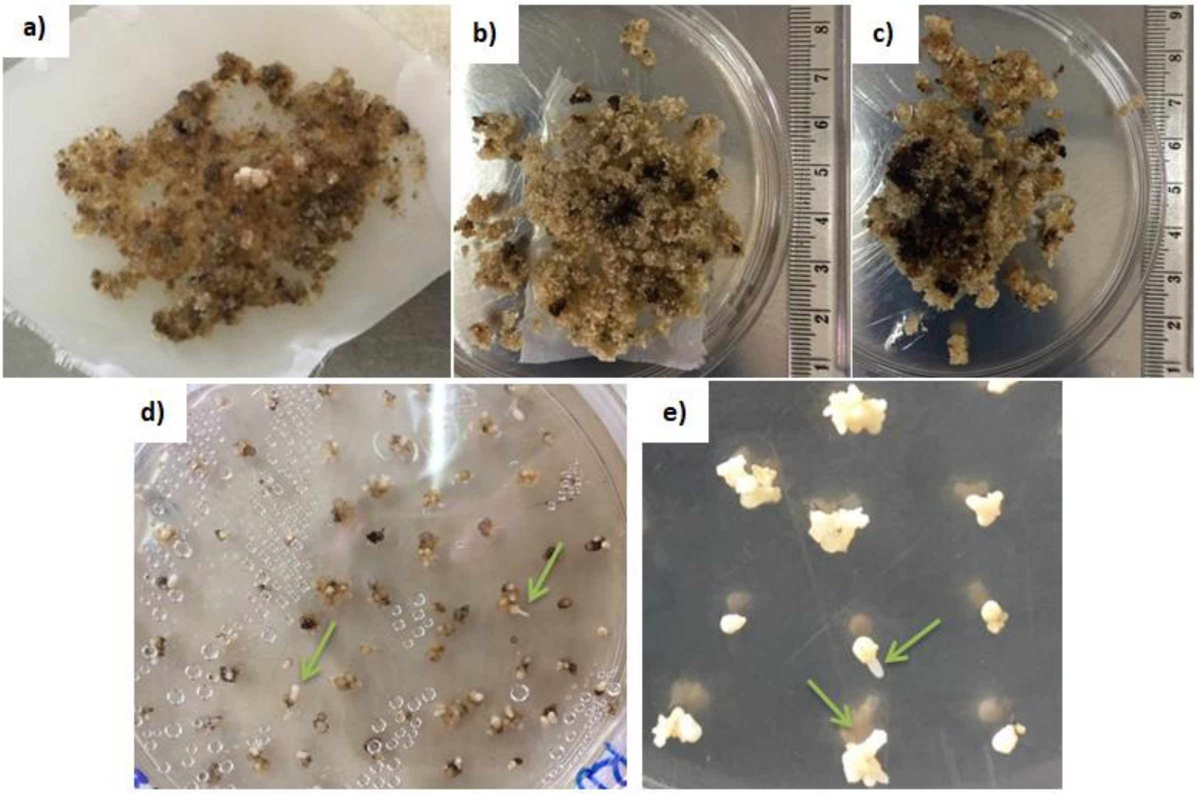


Figure 6.8. a) Embryogenic cells of the banana cultivar 'Sukali Ndiizi' transformed with the β-glucuronidase gene (*gusA*) cultivated on Embryo Development Medium (MA3) with selection 25 days after transformation. White embryos have started to appear. **b) Embryogenic cells of 'Sukali Ndiizi' expressing *gusA* cultivated on MA3 with selection 65 days after transformation.** Embryos were picked and transferred to Embryo Maturation Medium (RD1) with selection. **c) Non-transformed embryogenic cells of 'Sukali Ndiizi' (negative control) cultivated on MA3 without selection 65 days after initiation of transformation experiment.** Embryos were picked and transferred to RD1 medium without selection. **d) Germinating embryos (indicated by arrows) of 'Sukali Ndiizi' transformed with *gusA* after approximately one month on RD1 with selection.** Embryos were transferred to Germination Medium (MA4) with selection. **e) Germinating embryos (indicated by arrows) of non-transformed 'Sukali Ndiizi' (negative control) after one month on RD1 without selection.** Embryos were transferred to MA4 without selection.

Embryos of 'Sukali Ndiizi' transformed with *gusA* were found to regenerate (i.e. developed white shoots) on MA4 with selection after one to two months (Fig. 6.9a). After being transferred to Proliferation Medium (PM) and a 16h/8 light/dark cycle, the shoots turned green after one to two weeks (Fig. 6.9b). After approximately one month, shoots with three to four leaves were transferred onto Rooting Medium (RM) without selection, whereby they developed into whole plantlets after two to four weeks (Fig. 6.9c) (data for controls not shown) .

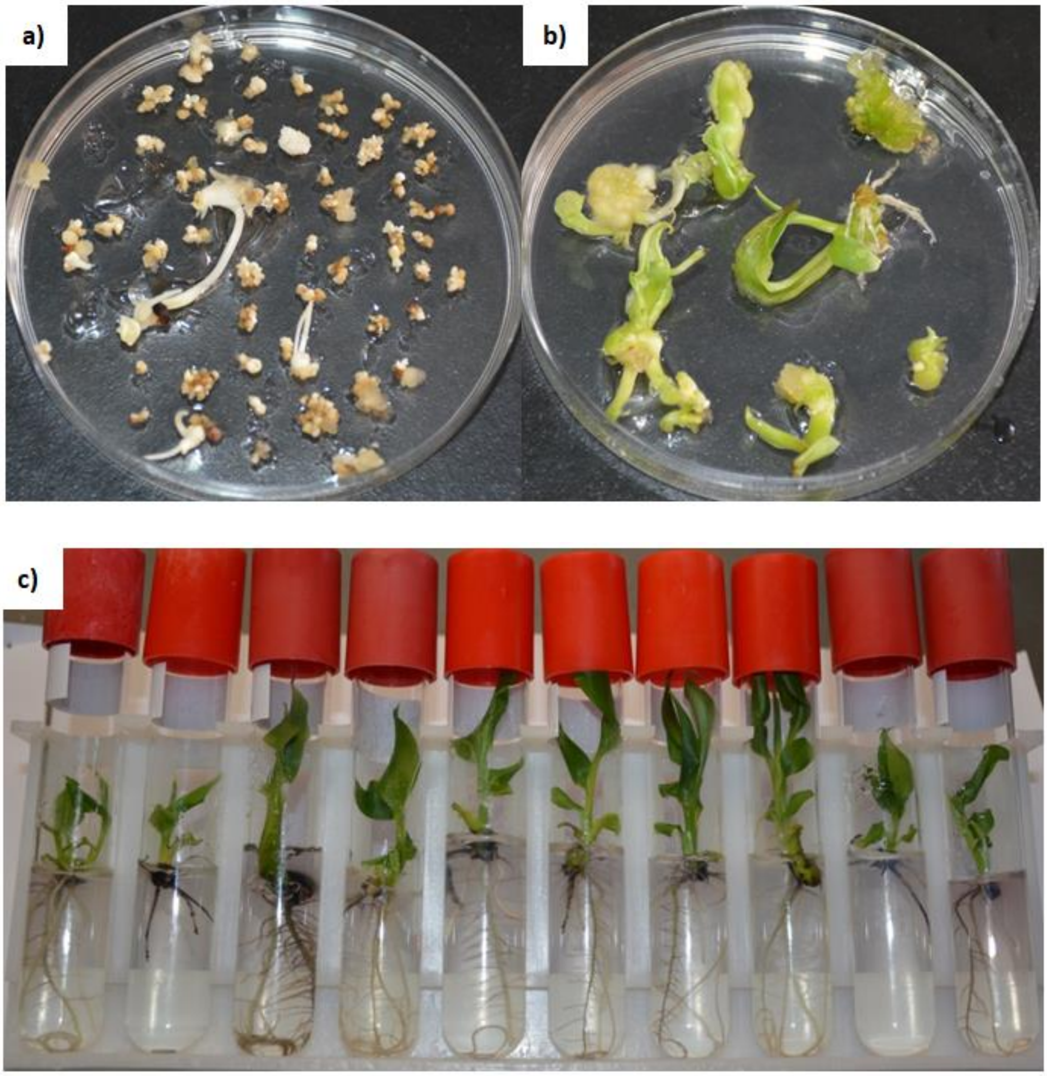


Figure 6.9. a) Embryos of the banana cultivar 'Sukali Ndiizi' transformed with the β-glucuronidase gene (*gusA)* regenerating on Germination Media (MA4) with selection. Photo acquired five months and one week after transformation. **b) Embryos of 'Sukali Ndiizi' transformed with *gusA* turned into green shoots in a 16h/8h light and dark cycle.** Photo acquired five months and one week after transformation. **c) Whole transgenic plantlets of 'Sukali Ndiizi' expressing *gusA* cultivated on Rooting Medium (RM).** Photo acquired seven months and three weeks after transformation.

The regeneration and development of 'Sukali Ndiizi' transformed with *gfp* occurred at a somewhat slower rate and at lower frequencies compared to 'Sukali Ndiizi' transformed with *gusA* (data not shown).

'Cavendish Williams'

As already touched upon, cultures of 'Cavendish Williams' transformed with *gusA* and *gfp* of the second transformation experiment had to be discarded due to necrosis (Appendices 2, Fig.G.2.1.1 and Fig. G.2.2.1). Thus, the results reported for 'Cavendish Williams' derive from the first transformation experiment.

Embryos started to develop in cultures of 'Cavendish Williams' ~25 and ~38 days after transformation with constructs for *gfp* and *gusA*, respectively (only a few embryos developed for cultures transformed with *gusA*) (Fig. 6.10a and Fig. 6.11a, respectively). Similarly, embryos were visible in control plates approximately 25 days after initiation of the transformation experiment (data not shown). Embryos were ready for picking and transfer to RD1 with/without selection after one-and-a-half to two months (Fig. 6.10b+c and Fig. 6.11b+c). Germination was observable in 'Cavendish Williams' transformed with *gfp* after approximately one month on RD1 with/without selection (Fig. 6.10d+e), but not for cultures transformed with *gusA* (i.e. no germination was observable before leaving IITA in mid-December of 2016).

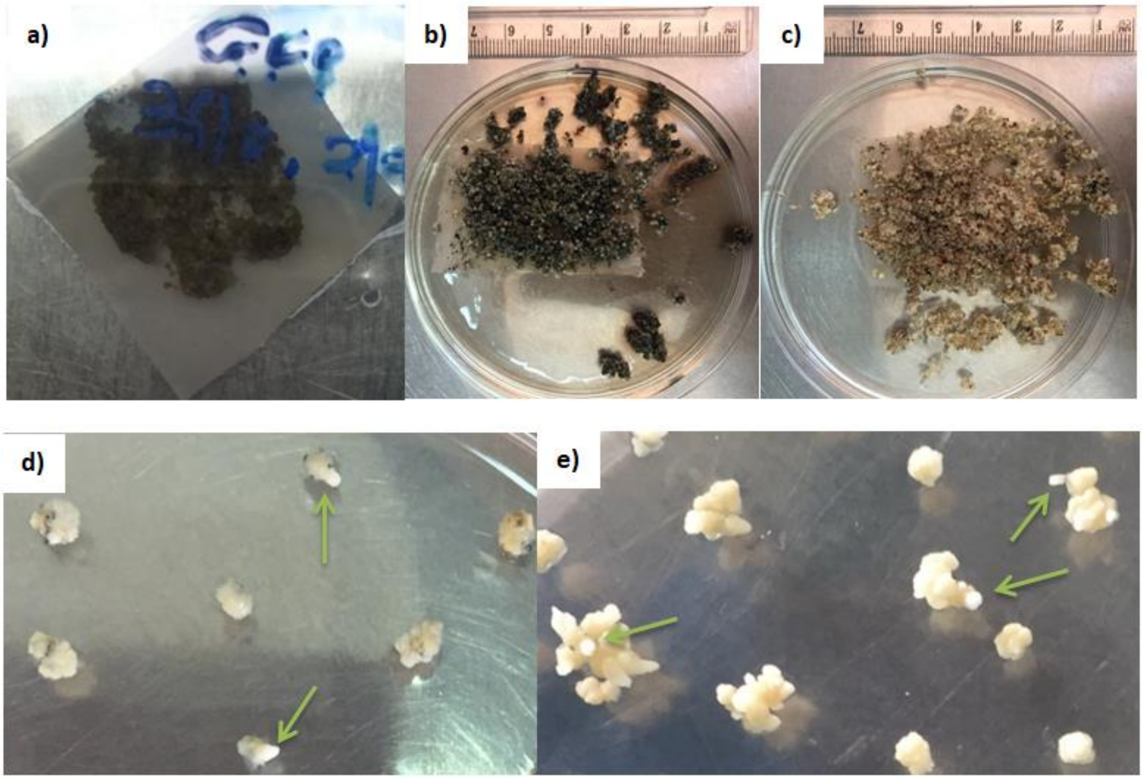


Figure 6.10. a) Embryogenic cell of the banana cultivar 'Cavendish Williams' transformed with the green fluorescent protein gene (*gfp*) cultivated on Embryo Maturation Medium (MA3) with selection 25 days after transformation. Embryos are present, but are hard to notice due to poor image quality. **b) Embryogenic cells of 'Cavendish Williams' transformed with *gfp* cultivated on MA3 with selection 63 days after transformation.** Embryos were picked and transferred to Embryo Maturation medium (RD1) medium with selection. **c) Non-transformed embryogenic cells of 'Cavendish Williams' (negative control) cultivated on MA3 without selection 63 days after initiation of transformation experiment.** Embryos were picked and transferred to RD1 without selection. **d) Germinating embryos (indicated by arrows) of 'Cavendish Williams' transformed with *gfp* after one month on RD1 with selection.** Embryos were transferred to Germination Medium (MA4) with selection. **e) Germinating embryos (indicated by arrows) of non-transformed 'Cavendish Williams' (negative control) after one month on RD1 without selection.** Embryos were transferred to MA4 without selection.

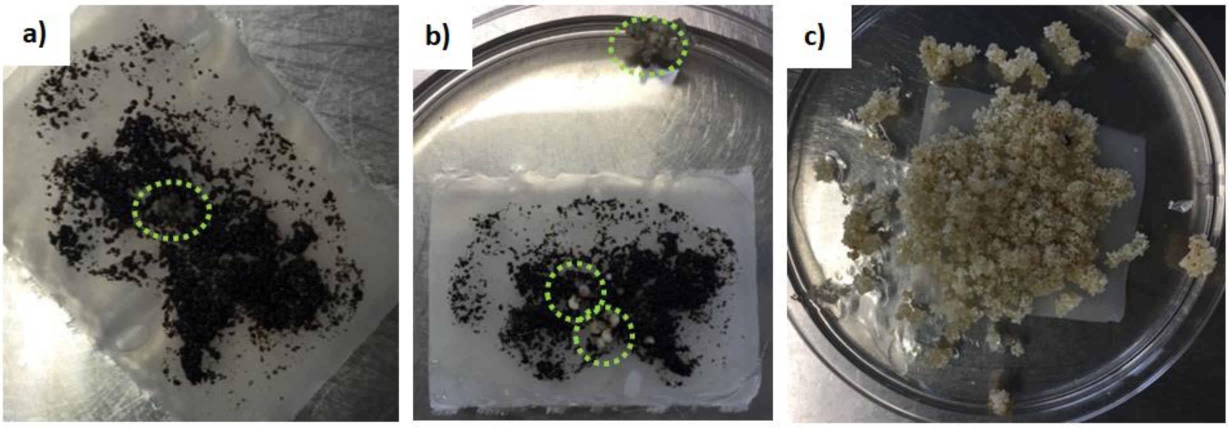


Figure 6.11. a) Embryogenic cells of the banana cultivar 'Cavendish Williams' transformed with the β-glucuronidase gene (*gusA*) cultivated on Embryo Maturation Medium (MA3) with selection 38 days after transformation. A few embryos are present (indicated by dashed circle). **b) Embryogenic cells of 'Cavendish Williams' transformed with *gusA* cultivated on MA3 with selection 63 days after transformation.** Embryos (indicated by dashed circles) were picked and transferred to Embryo Maturation Medium (RD1) with selection. **c) Non-transformed embryogenic cells of 'Cavendish Williams' (negative control) cultivated on MA3 without selection 63 days after initiation of transformation experiment.** Embryos were picked and transferred to RD1 medium without selection.

Unfortunately, none of the cultures of 'Cavendish Williams', including controls, successfully regenerated on MA4 media.

6.2.2.4. β-glucuronidase (GUS) assay

Transient GUS assay
Cells of both 'Sukali Ndiizi' and 'Cavendish Williams' produced blue precipitate after overnight incubation with the GUS mastermix (Fig. 6.12-6.14).

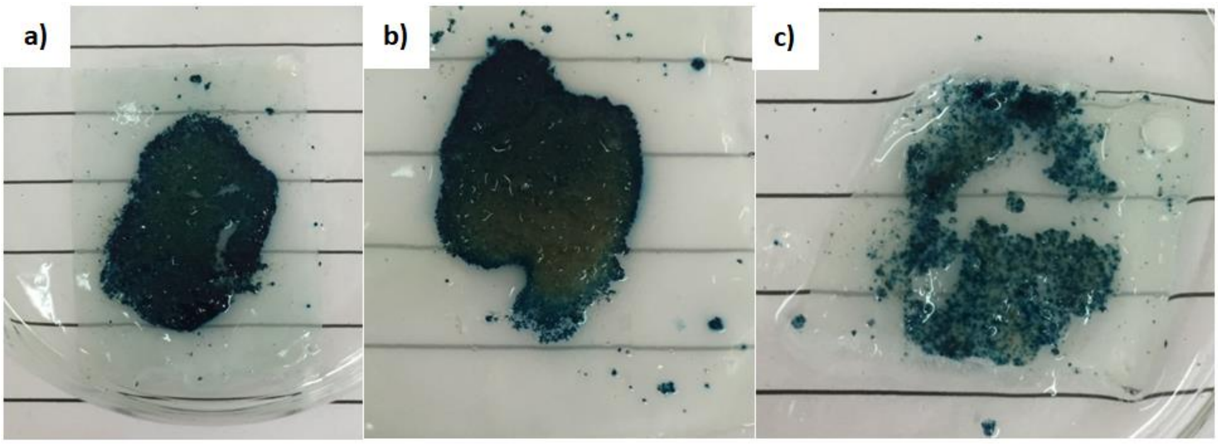


Figure 6.12. Transient expression of the β-glucuronidase (*gusA*) gene in putatively transformed embryogenic cells of the banana cultivars a-b) 'Sukali Ndiizi' and c) 'Cavendish Williams' three days after co-cultivation with *Agrobacterium*.

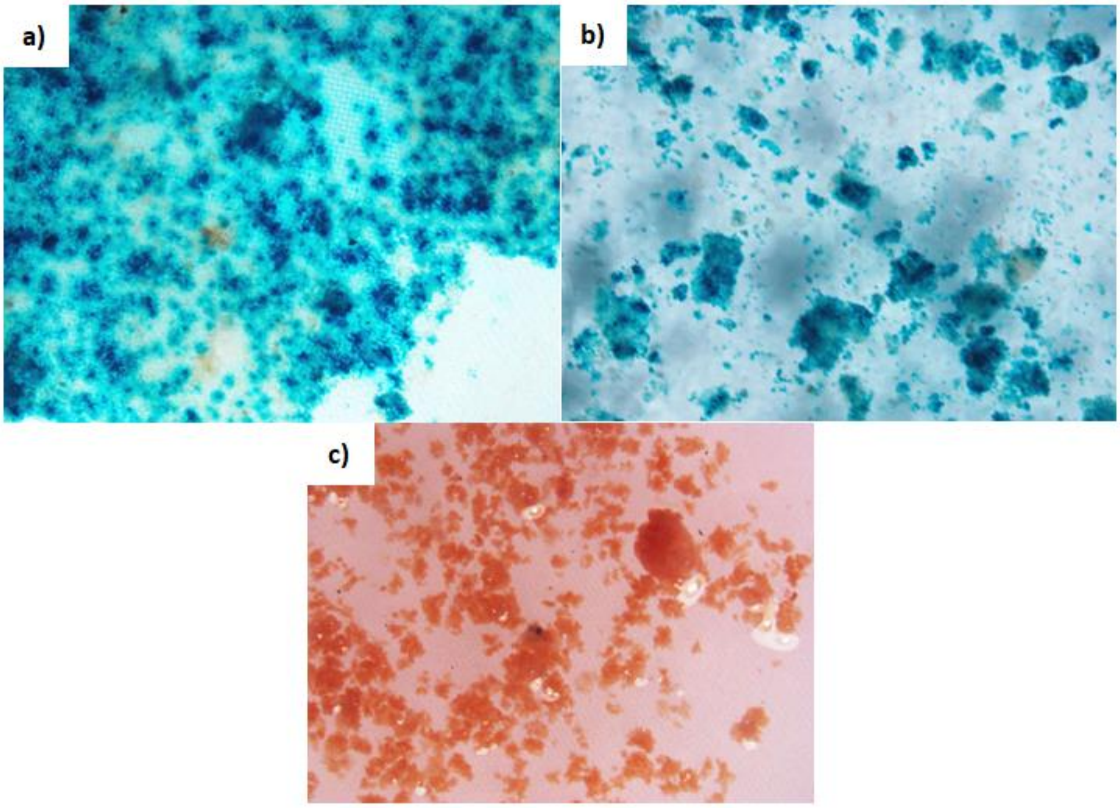


Figure 6.13. a-b) Transient expression of β-glucuronidase (*gusA*) gene in putatively transformed embryogenic cells of the banana cultivar 'Cavendish Williams' three days after co-cultivation with *Agrobacterium*. c) Non-transformed embryogenic cells of 'Cavendish Williams' (negative control). No blue precipitate is present. Note that image was obtained from a different transformation experiment and only included for demonstrative purposes.

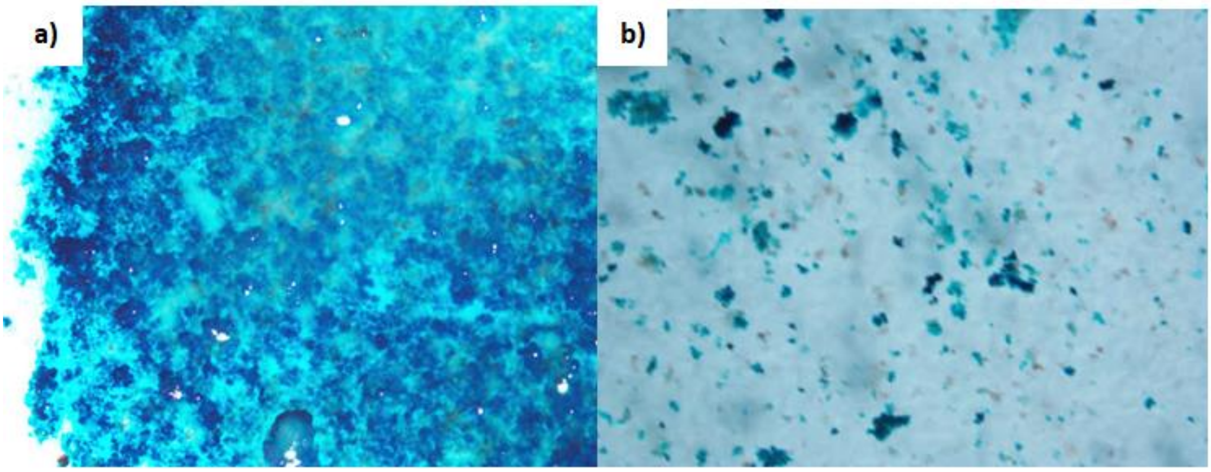


Figure 6.14. a-b) Transient expression of the β-glucuronidase (*gusA*) gene in putatively transformed embryogenic cells of the banana cultivar 'Sukali Ndiizi' three days after co-cultivation with *Agrobacterium.*

Stable GUS assay

The stable GUS assay demonstrated expression of the *gusA* gene in the leaves (Fig. 6.15a-b) and roots (Fig. 6.15c) excised from whole transgenic plantlets of 'Sukali Ndiizi'.

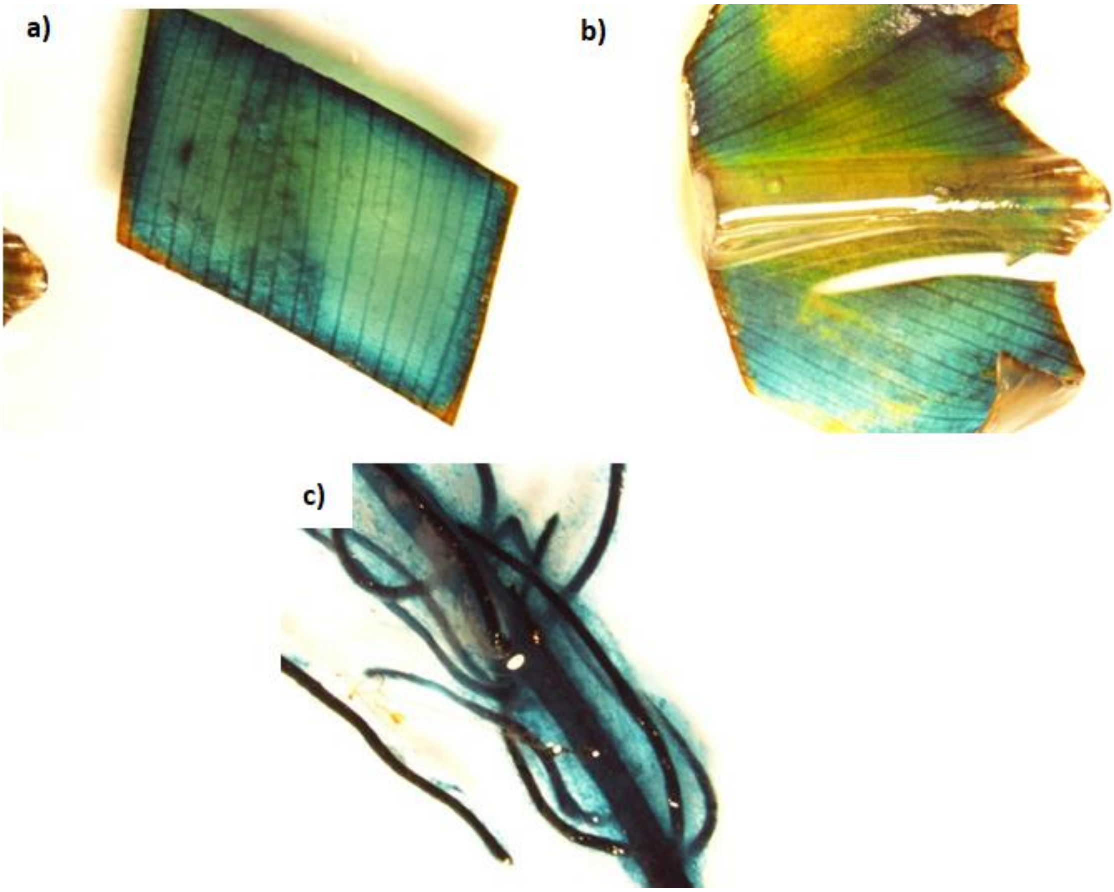


Figure 6.15. Stable expression of the β-glucuronidase gene (*gusA*) in a-b) leaf segments and c) roots excised from transgenic plantlets of the banana cultivar 'Sukali Ndiizi'.

None of the embryogenic cells of 'Cavendish Williams' regenerated into whole plantlets, thus it was not possible to carry out a stable GUS assay for this cultivar.

6.2.2.5. Green Fluorescent Protein (GFP) assay

Transient GFP assay: 'Sukali Ndiizi'

Putative green fluorescent signals were observed in cultures of 'Sukali Ndiizi' six days after transformation (Fig. 6.16a+b). Fluorescent-like signals were also apparent in control plates (Fig. 6.16c), though this was somewhat challenging to deduce due to the poor quality of the image (as a result of evaporation on the lid).

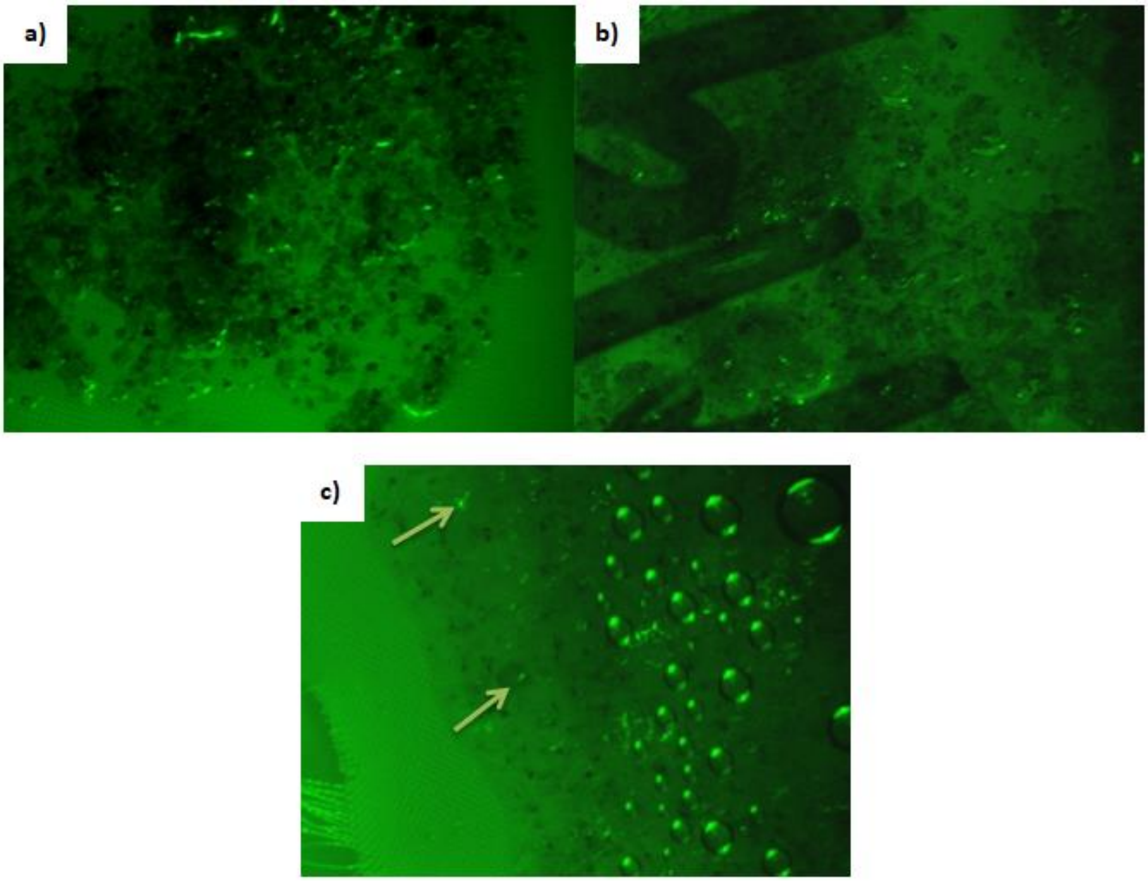


Figure 6.16. a-b) Putative transient expression of the green fluorescent protein gene (*gfp*) in transformed embryogenic cells of the banana cultivar 'Sukali Ndiizi' six days after transformation. c) Non-transformed embryogenic cells of 'Sukali Ndiizi' (negative control) six days after initiation of transformation experiment. The image was captured at the periphery of the nylon mesh containing the embryogenic cells due to evaporation on the lid (bubbles to the right-hand side). Arrows indicate fluorescent-like signals.

At 87 days after transformation, some of the embryogenic cells appeared to produce somewhat brighter signals in both putatively transformed cultures of 'Sukali Ndiizi' (Fig. 6.17a) and controls (Fig. 6.17b).

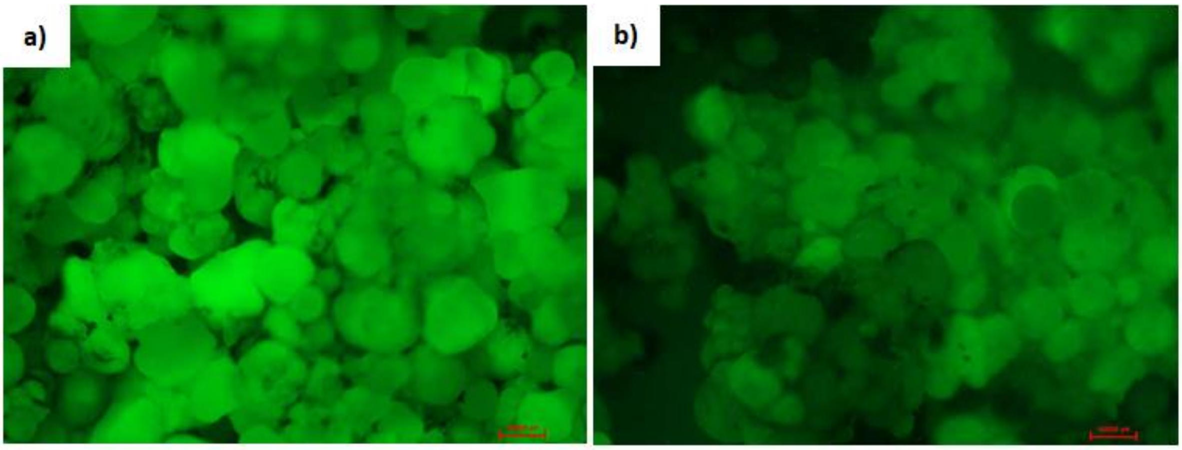


Figure 6.17. a) Putative transient expression of the green fluorescent protein gene (*gfp*) in transformed embryogenic cells of the banana cultivar 'Sukali Ndiizi' 87 days after transformation. b) Non-transformed embryogenic cells of 'Sukali Ndiizi' (negative control) 87 days after initiation of transformation experiment.

Transient GFP assay: 'Cavendish Williams'

Putative green fluorescent signals were observable in cultures of 'Cavendish Williams' 16 days after transformation (Fig. 6.16a+b) (data not shown for control).

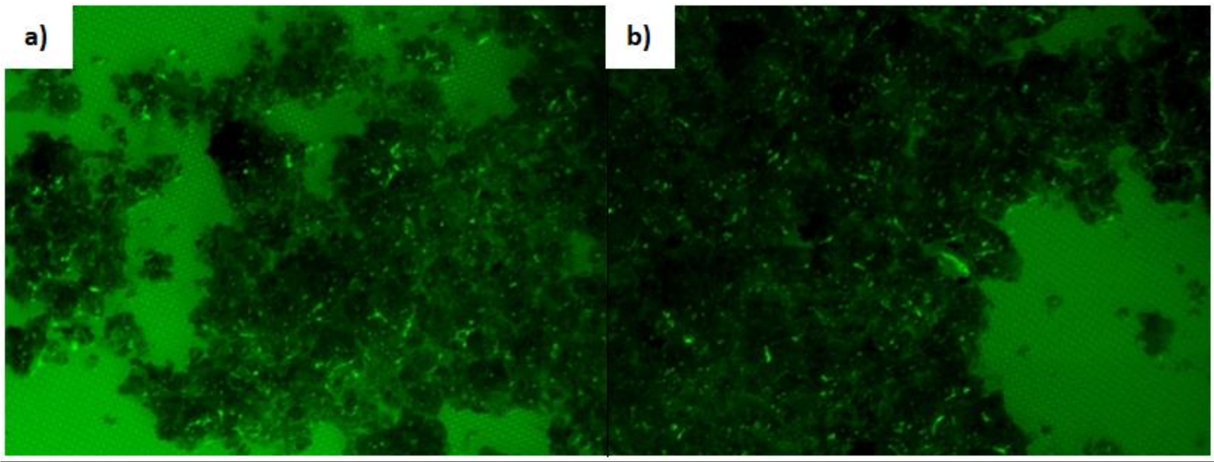


Figure 6.18. a-b) Putative transient expression of the green fluorescent protein gene (*gfp*) in transformed embryogenic cells of the banana cultivar 'Cavendish Williams' 16 days after transformation.

At 97 days after transformation, distinct fluorescent signals were apparent in cultures of transformed cells of 'Cavendish Williams' (Fig. 6.19a-c), but not in control (Fig. 6.19d).

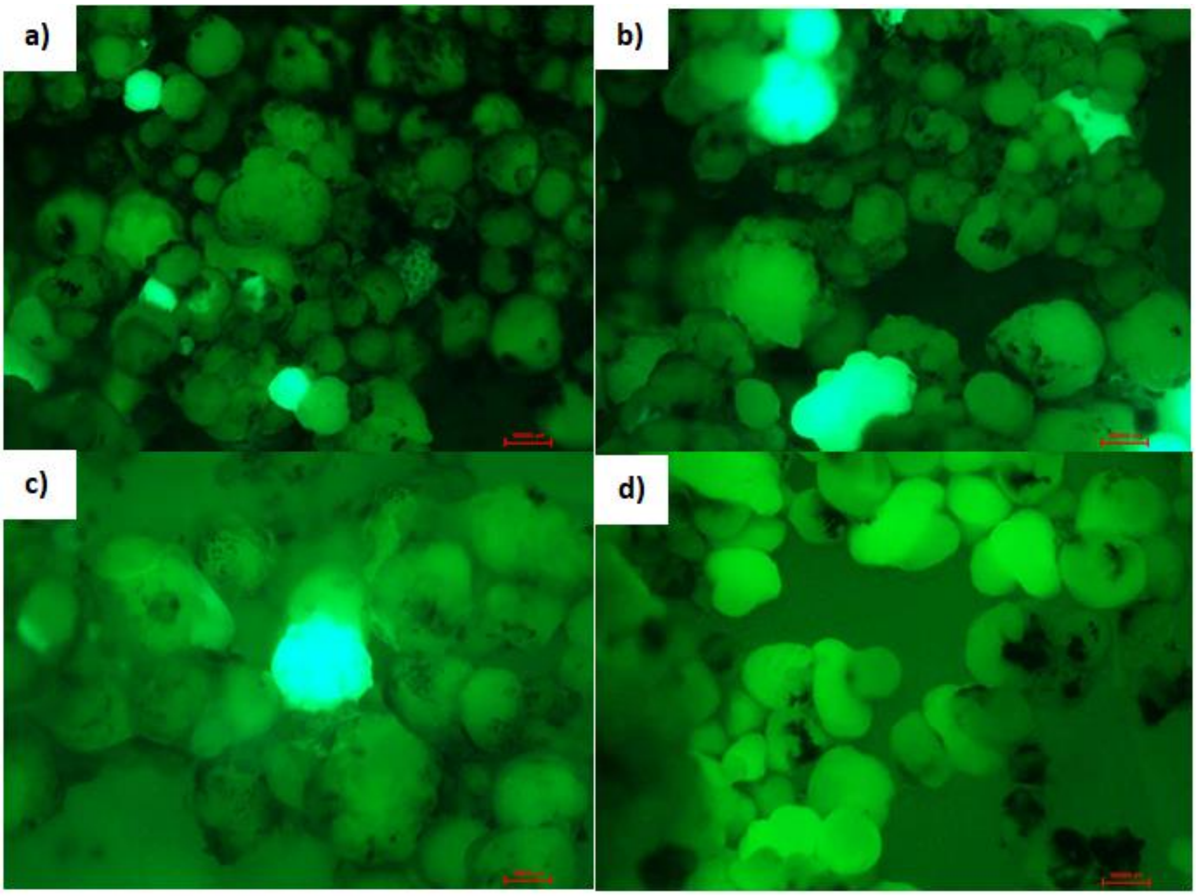


Figure 6.19. a-c) Transient expression of the green fluorescent protein gene (*gfp*) in transformed embryogenic cells of the banana cultivar 'Cavendish Williams' 97 days after transformation. d) Non-transformed embryogenic cells of 'Cavendish Williams' (negative control) 97 days after initiation of transformation experiment.

Stable GFP assay

Lines of 'Sukali Ndiizi' did not produce fluorescence during the stable GFP assay or in the dark (data not shown), while none of the transformed embryos of 'Cavendish Williams' regenerated into whole plantlets, thus it was not possible to carry out the stable GFP assay.

6.2.2.6. Polymerase Chain Reaction (PCR) analysis

Extraction of genomic DNA (gDNA) from lines of 'Sukali Ndiizi' transformed with pCAMBIA2301 and subsequent PCR analysis was carried out approximately eight months after transformation, and demonstrated amplicons of the expected size (~500 bp) for all samples and the positive control (Fig. 6.20).

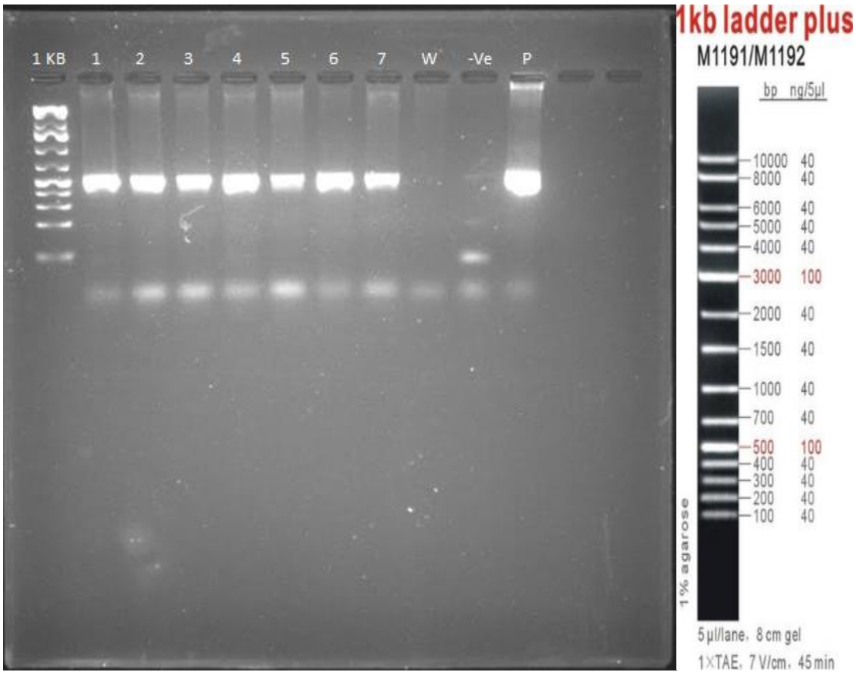


Figure 6.20. PCR analysis of genomic DNA (gDNA) from lines of transformed and non-transformed (negative control) plants of the banana cultivar 'Sukali Ndiizi' using β-glucuronidase (*gusA*) specific primers. From left to right: 1 Kb ladder (see insert right); 1-7, samples; W, wild type (non-transgenic control plant); -Ve, negative control (blank); P, positive control (plasmid). The amplicons are of the expected size (~500 bp) which provides strong evidence of complete T-DNA insertion.

Extraction of genomic DNA (gDNA) from lines of 'Sukali Ndiizi' transformed with *gfp* and subsequent PCR analysis was carried out approximately nine months after transformation, and did not demonstrate amplicons of the expected size (~500 bp) for any of the five samples (Fig. 6.21). An amplicon of the expected size was only observed for the positive control (Fig. 6.21).

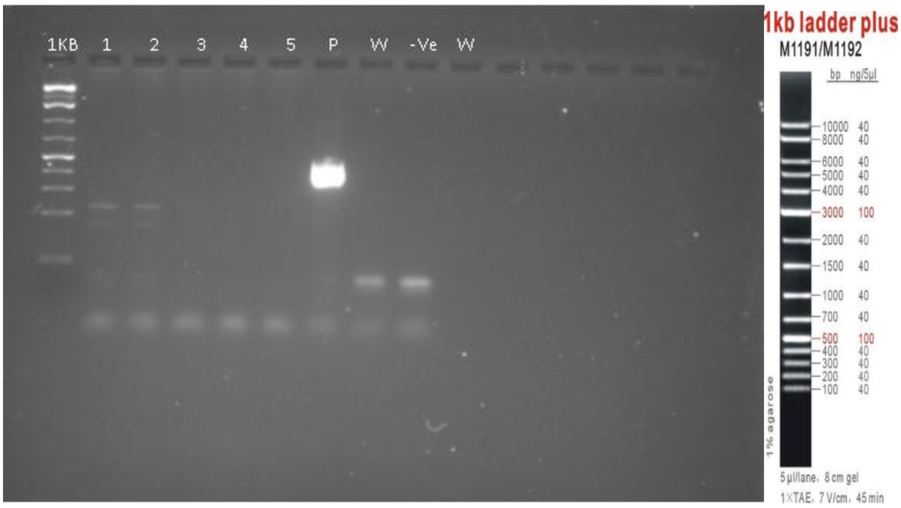


Figure 6.21. PCR analysis of genomic DNA (gDNA) from lines of putatively transformed and non-transformed (negative control) plants of the banana cultivar 'Sukali Ndiizi' using green fluorescent protein gene (*gfp*) specific primers. From left to right: 1 KB, 1 kb+ ladder (insert right); 1-5, samples; P, positive control (plasmid); -Ve, negative control (blank); W, wild type (non-transgenic control plant). An amplicon of the expected size (~500 bp) is only apparent for the positive control.

6.2.3. Discussion

Establishing a robust, high-throughput protocol which allows testing of several constructs and the subsequent production of a large number of independent transgenic lines, is essential for any transformation protocol. Tripathi *et al*. (2015) have established a protocol in banana and plantain (*Musa spp*.) using *Agrobacterium*-mediated transformation of embryogenic cell suspensions (ECSs), which has been demonstrated during the practical work conducted for this thesis. The subsequent paragraphs will discuss the results obtained; the advantages and limitations of the methods; other experimental confounding factors; alternative platforms for regeneration and transformation in Musa *spp*.; how the techniques can be applied to other crop species; and finally some outlooks.

6.2.3.1. Results obtained during the practical work

Plasmid extraction from *Agrobacterium* cultures

The plasmid extraction and subsequent analysis by agarose gel electrophoresis demonstrated bands at 10000-12000 bp for all samples (Fig. 6.5 and Fig. 6.6), which is consistent with the size of the constructs (i.e. ~11633 bp for pCAMBIA2301 and ~10294 bp for pCAMBIA2301-gfp) and indicates successful uptake of the plasmids by the *Agrobacterium* cultures.

Some smearing, and multiple and smiling bands were apparent in the gels (Fig. 6.5 and Fig.6.6). Such observations can be explained by several aspects, including (i) the plasmid DNA has not been successfully isolated from a single colony (IITA researcher, pers. comm.), which is considered a likely causative factor as it was difficult to obtain single colonies following streaking of the LB plates; (ii) some of the plasmid DNA has got stuck in the wells (Thermo Fisher Scientific, s.a.); (iii) the wells have been overloaded with DNA (however, only small quantities of DNA was pipetted); (iv) contamination by, for instance, genomic DNA, proteins, polysaccharides or salts, which is considered another likely causative factor as the nanodrop reading indicated presence of contamination (Table 6.3 and Table 6.4); (v) shearing of DNA (e.g. due to various processing steps such as vortexing, chemical breakdown, and/or a result of DNA moving through small openings (e.g. during pipetting) (Lengsfeld & Anchordoquy, 2002; IITA researcher, pers. comm.); and (vi) plasmid DNA appearing in different conformations (i.e. circular, nicked circular and linear) that exhibit different run time through the gel (Higgins & Vologodskii, 2015). The low intensity of the bands of the second gel (Fig. 6.6) can be explained by factors such as inadequate isolation of the plasmid, poor quantity and quality of the DNA (Table 6.4), and/or errors during loading (e.g. failure to load wells properly).

To counteract some of the above-mentioned issues, it could have proven useful to repeat extraction and processing of the plasmid DNA (e.g. ensure adequate washing and purification, and resuspension of the sample); avoid vigorous vortexing/stirring; ensure that appropriate aseptic techniques are being employed; use fresh stocks, pipette tips and so forth; repeat process of single colony picking; increase the concentration of agarose in the gel, and/or change the voltage and/or run time of electrophoresis (Roche Diagnostics GmbH, 2011; Thermo Fisher Scientific, s.a.; IITA researcher, pers. comm.).

Growth and development of embryogenic cells

Embryos appeared in cultures of 'Sukali Ndiizi' and 'Cavendish Williams' transformed with both *gfp* and *gusA*, as well as in control plates (Fig. 6.7c-6.8c and Fig. 6.10c-6.11c), approximately ~25 days after transformation (Fig. 6.7a, 6.8a, 6.10a,respectively), with the exception of 'Cavendish Williams' transformed with *gusA,* whereby only a few embryos were observable after ~38 days (Fig. 6.11a).

Embryos of all cultures were ready for picking and transfer to RD1 after approximately one-and-a-half to two months on MA3 with/without selection (Fig. 6.7b, 6.8b, 6.10b, 6.11b).

Embryos started to show signs of germination after approximately one month on RD1 with selection (i.e. shortly before leaving IITA in mid-December of 2016) (Fig. 6.7d, Fig. 6.8d and Fig.6.10d), with the exception of cultures of 'Cavendish Williams' transformed with *gusA*. In control plates, a higher number of embryos developed (data not shown), and were found to germinate somewhat earlier than for transformed cultures (Fig. 6.8e and Fig. 6.10e). Such findings are as expected considering that the non-transformed embryogenic cells are not exposed to the stress of antibiotics.

Embryos of 'Sukali Ndiizi' transformed with *gusA* were found to regenerate after one to two months on MA4 with selection (Fig. 6.9a), and successfully developed into whole plantlets after approximately two to two-and-a-half months (Fig. 6.9b+c). The regeneration and development of 'Sukali Ndiizi' transformed with *gfp* into whole plantlets occurred at a somewhat slower rate and at lower frequencies than for 'Sukali Ndiizi' transformed with *gusA* (data not shown). In the case of 'Cavendish Williams', none of the cultures including controls successfully regenerated on MA4.

The failed germination and regeneration, as well as the necrotic cultures of 'Cavendish Williams' of the second transformation experiment, could indicate poor quality of the ECSs (note that the same ECSs was used for the first and second transformation experiment), which will be discussed in later sections (along with other potential explanatory variables). That being said, though one would have expected a few embryos to regenerate despite low quality ECSs, it is often necessary with several experiments using large amount of cells to generate as few as 100 lines in banana (IITA researcher, pers. comm.). Thus, when such considerations are taken into account, the attainment of a few transgenic lines in 'Sukali Ndiizi' transformed with *gusA* can be considered a relatively successful outcome for an experiment of this size.

Reporter gene assays

GUS assays

For the transient GUS assay, cells of both 'Sukali Ndiizi' and 'Cavendish Williams' produced blue precipitate (Fig. 6.12-6.14), which indicate successful uptake of the plasmid and transient expression of the *gusA* gene. Contrary, blue precipitate is not produced in non-transformed cells, as exemplified in Fig. 6.13c. The stable GUS assay showed expression of the *gusA* gene in the leaves (Fig. 6.15a-b) and roots (Fig. 6.15c) excised from whole transgenic plantlets of 'Sukali Ndiizi', thus indicating stable gene integration and expression.

GFP assay

For the GFP assays, apparent green fluorescent signals were observable for cells of both 'Sukali Ndiizi' and 'Cavendish Williams' 6 and 16 days after transformation (Fig. 6.16a+b and Fig. 6.18a+b), respectively, whereby cultures of 'Cavendish Williams' appeared to contain the highest number of fluorescent signals. However, apparent fluorescent signals or some sort of artefacts were also observed in control plates of 'Sukali Ndiizi' (Fig. 6.16c), though it was hard to deduce due to the poor quality of the image (as a result of evaporation on the lid). Unfortunately, no images of 'Cavendish Williams' controls were included at this point.

At 97 days after transformation, distinct fluorescent signals were apparent in cultures of putatively transformed cells of 'Cavendish Williams' (Fig. 6.19a-c), but not in control (Fig. 6.19d). The signals were less distinguishable in cultures of putatively transformed 'Sukali Ndiizi' (87 days after transformation) (Fig. 6.17a). The noticeable difference in the intensity of the signals of the two cultivars could be due to factors such as differences in copy number, where in the genome the expression cassettes have become integrated, and the way in which the image is captured (e.g. the position of the embryos), or possibly reflect cultivar-dependent effects.

That being said, the signals observable for the putatively transformed cells of 'Sukali Ndiizi' (Fig. 6.17a) were relatively similar to what was observed in non-transformed control plates (Fig. 6.17b). This finding could indicate that the embryogenic cells of 'Sukali Ndiizi' are not expressing the *gfp* gene, which is further supported by the fact that the whole putatively transgenic plants did not fluoresce in complete darkness (IITA researcher, pers. comm.). Thus, what appears to be fluorescent signals in the cultures of 'Sukali Ndiizi' could be a result of factors such as exposure time of the camera, and/or fluorescent-like signals from the *Agrobacterium*, the lid and from auto-fluorescent molecules such as chlorophyll (however, tissues of banana do not express endogenous green fluorescent-like activity) (Tripathi, pers. comm.).

Additionally, the extent of blackening and browning (i.e. cell death) were more severe in the embryogenic cultures of 'Sukali Ndiizi' transformed with *gfp* compared to 'Cavendish Williams' transformed with *gfp* and for 'Sukali Ndiizi' transformed with *gusA* (data not shown). Though this may reflect cultivar or construct-dependent effects, it could imply that that the cells of 'Sukali Ndiizi' transformed with *gfp* were being killed off by the selective agent.

Taken together, the above-mentioned observations indicate that the transformation of 'Sukali Ndiizi' for the expression of *gfp* was unsuccessful. In order to determine this, molecular analyses such as PCR is need (see next paragraph).

PCR analysis

As the cultures of 'Cavendish Williams' failed to regenerate on MA4 and develop into whole transgenic plants, it was not possible to verify the successful integration of the transgenes using PCR. The PCR analysis performed for 'Sukali Ndiizi' transformed with *gusA* demonstrated amplicons of the expected size, i.e. ~500 bp (i.e. the size of the internal fragment of *gusA* amplified by the PCR), thus provided strong evidence of complete T-DNA insertion (Fig. 6.20). The PCR analysis performed for 'Sukali Ndiizi' transformed with *gfp* did not produce amplicons for any of the samples expect for the positive control (Fig. 6.21), which indicates that the transformation was unsuccessful as previously suggested.

Stable transformation using the *gfp* gene is challenging (IITA researcher, pers. comm.), and a number of factors could help explain the failed transformation, including the ECSs (e.g. the age and quality of the cells), the *Agrobacterium*, the construct, and/or error occurring during the transformation and regeneration protocol. Such factors will be discussed in the subsequent sections.

6.2.3.2. Limitations of the methods

Labour and time-intensive

The protocol is highly labour-intensive and time-consuming – Tripathi *et al*. (2015) reported that it took 13-15 months to obtain complete plantlets from ECSs in different varieties of banana, during which time laborious steps of sub-culturing and picking of single embryos have to be carried out.

Other studies have reported as much as 14-42 months for banana cultivars and 18-27 months for plantains (Strosse *et al.,* 2006).

Age and quality of embryogenic cell suspensions (ECSs)
The age and quality of the ECSs is an influential factor on the successful outcome of the experiment. Generally, younger and finer granular cells exhibit the highest transformation and regeneration capacity, as opposed to older and larger aggregates of cells which tend to turn brown and black (Tripathi, pers. comm.). This effect was observed during both the GUS and GFP assay whereby clumped cells appeared to remain untransformed.

More specifically, a high quality ECSs can be characterised as having (i) a high proportion of proliferating embryogenic cells (>80%); (ii) bright to light yellow colouration (pale and white suspensions indicate presence of non-regenerable cells high in starch); (iii) <1 minute precipitation of cells when the suspension is removed from the orbital shaker, which indicates high density of cellular content; (iv) >90% viability in a fluorescein diacetate (FDA) test (i.e. whereby diluted FDA is added to a sample of the suspension, which is subsequently exposed to UV light; bright green fluorescence indicate high viability); (v) 1.5-2 multiplication ratio every two weeks; and (vi) high regeneration capacity (i.e. measured as the number of embryos per ml of plated cells; for instance, Côte *et al*. (1996) and Grapin *et al*. (1996) showed that 1 ml of settled cells can result in anywhere from 100 to 300 000 embryos) (Strosse *et al*., 2003).

Consequently, sub-culturing and synchronisation of the liquid suspensions is necessary to improve the quality and to obtain homogenous ECSs (takes about 6-9 months). Washing and refreshing of the suspensions keeps the cell concentration at a adequate level, avoids aggregates of cells from forming, renews resources and nutrients, prevents build-up of metabolites (e.g. phenols), and allows for screening of contamination. Agitation during culturing further helps prevent aggregation of cells. However, the quality of the ECSs is reduced with time and the number of sub-cultures as this increases the probability of contamination, and lowers the growth rate and regeneration capacity (Strosse *et al*., 2003).

The embryogenic cells of 'Sukali Ndiizi' and 'Cavendish Williams' used in the practical work were approximately 6 and 14 months old, respectively; both of which can be considered relatively old (IITA researcher, pers. comm.).

Cultivar/genotype-dependent effects
A major challenge of somatic embryogenesis is genotype-dependent effects, which influence the intrinsic embryogenic potential and various other aspects of the protocol, some of which are listed below.

Choice of suitable embryogenic callus for establishment of embryogenic cell suspensions (ECSs)
It is essential to identify suitable embryogenic calli for the establishment of the ECS in order to ensure equilibrium between "the right size" and the "right developmental stage" (i.e. in terms of quality and volume) (Strosse *et al*., 2003). Embryogenic calli can be identified as being white or creamish yellow, friable and with pro-embryos present (Tripathi *et al*., 2015). Yellow, clumped/nodular and hard-packed callus should be avoided. However, colour development can be cultivar-dependent, thus is not necessarily a clear indicator of the quality (Tripathi, pers. comm.). Consequently, it is important to consider several factors concurrently, such as colour and friability.

Apparent cultivar-dependent effects observed during sub-culturing on MA3

There appeared to be cultivar-dependent phenotypical differences of the embryogenic cells cultured on MA3. 'Sukali Ndiizi' developed a light yellowish colouration (e.g. Fig. 6.7b), while 'Cavendish Williams' had a darker, greenish tint (e.g. Fig. 6.10b). Furthermore, cultures of 'Cavendish Williams' generally appeared to contain more "hard-packed" embryos that were easier to pick and transfer onto RD1/RD2 and MA4 (however, the embryos were at times so tightly packed that transfer of single ones became challenging) (data not shown).

Transformation and regeneration efficiency

Transformation and regeneration efficiency is strongly cultivar-dependent. Tripati *et al*. (2015) found that the regeneration capacity – calculated as the number of plantlets regenerated per ml of settled cell volume (SCV)– was between 20000-50000 plantlets per 1 ml SCV of ECS. 'Sukali Ndiizi' exhibited the maximum regeneration efficiency, while 'Cavendish Williams' displayed intermediate efficiency (the least responsive was 'Gros Michel', AAA group).The transformation efficiency – calculated as the number of PCR positive lines regenerated on kanamycin-selective medium per ml SCV of ECS– was found to be 60-70 and 30-40 lines per ml SCV for 'Sukali Ndiizi' and 'Cavendish Williams', respectively (20-30 lines developed per ml SCV in 'Gros Michel'). Thus, the transformation efficiency appears to be correlated with the regeneration efficiency of the embryogenic cells.

The set-up and outcome of the practical work conducted for this thesis did not facilitate or allow for exact calculations of the transformation and regeneration efficiency. One might argue that the fact that 'Sukali Ndiizi' was the only cultivar for which embryos successfully regenerated, could tally well with the results obtained by Tripathi *et al*. (2015). However, the limited number of plates and replicates reduce the reliability of using such and similar observations (e.g. the results from the GUS and GFP assays and PCR analysis) as indicators of transformation and regeneration efficiencies. Furthermore, the failure of most lines to regenerate is likely explained by other factors besides (or in addition to) genotype-dependent effects (elaborated on in subsequent sections).

Somaclonal variation and aberrant plants

A drawback of somatic embryogenesis is the relatively high level of aberrant plants (compared to e.g. shoot tip culture) due to somaclonal variation at the morphological, cytological (i.e. number and structure of chromosomes), cytochemical (e.g. genome size), biochemical (i.e. proteins and isozymes) and molecular level (including nuclear, mitochondrial and plastid genomes) (Rani & Raina, 2000; George *et al*., 2008a). For instance, proportions from 15% to 100% of somaclonal variants have been reported in 'Grande naine' after 15 months of sub-culturing (Côte and colleagues, unpublished data; as cited by Strosse *et al*., 2003). As a result of the relatively high level of somaclonal variation, some cultivars do not currently meet the quantitative and qualitative standard required for mass production (Strosse *et al*., 2003).

Someclonal variation is a result of a variety of factors, including genotype, ploidy level, *in vitro* culture age and type, and the type of explant (Rani & Raina, 2000; Sahijram *et al*., 2003). Furthermore, when embryogenesis is initiated from suspension cultures or from callus in which there has been a period of unorganised growth, or in cultures that have been maintained for several months (again reflecting the importance of age and quality of the ECSs), the chance of genetic abnormalities increases (Orton, 1985). Indeed, a direct relationship between the time spent in subculture and the level of somaclonal variation have been demonstrated in ECSs of banana (Strosse *et al*., 2003). Thus, in order to minimise the level of somaclonal variation, Tripathi *et al.* (2015) limited transformation and regeneration experiments to one to one-and-a-half years after establishment, which resulted in aberrations in 3-5% of rooted plants (including retarded growth, and thinner and variegated leaves).

General limitations of *Agrobacterium*-mediated transformation

Limiting factors of *Agrobacterium*-mediated transformation, particularly so in the case of monocots, include the type of (i) *Agrobacterium* strain (e.g. level of virulence), (ii) explant, (iii) binary vector, (iv) promoters, and (v) selectable marker genes and selective agents; and conditions of (vi) inoculation and co-culturing and (vii) regeneration and tissue culture (Hiei *et al*., 1997; Cheng *et al*., 2004). However, such factors are not considered likely explanations for the failed regeneration and transformation, as they have been optimised as part of the established protocol.

6.2.3.3. Other confounding factors: Controls, randomisation and others

Lack of appropriate controls

Unfortunately, due to limited amount of ECSs available, the appropriate controls were not always included, which limited the reliability of the experiment and the results obtained (though the literature can be used for comparable measures, e.g. Tripathi *et al.,* 2015). For instance, no negative controls were included for 'Cavendish Williams' during the second transformation experiment (during the GUS assay, the putatively transformed embryos of 'Cavendish Williams' were compared to a control obtained from a different experiment, which is not optimal). Non-transformed embryogenic cells (negative control) are important as a way of deducing the effect of the construct and/or process of transformation on the experimental outcome, thus could have helped provide insight into why the cultures of 'Cavendish Williams' of the second transformation experiment became necrotic. For instance, if controls had been found to be viable, it might have implied that an error had occurred during the process of transformation. Alternatively, if controls were found to suffer the same fate as transformed cells, then perhaps a more likely explanation would have been poor quality of ECSs or inadequate culturing conditions (e.g. the component of the media). A negative control consisting of non-transformed cells is also important to include during e.g. the GUS assay as a way of detecting endogenous expression of GUS-like activity (Schöpke *et al*., 1993).

Optimally, a positive control should also have been included, i.e. whereby a model plant species like *N. tabacum* is transformed using the same construct. Such a control is important for e.g. the histochemical GUS assay as a way of monitoring the extent of the reaction (Karcher, 2002). Furthermore, transformation experiments may also include a negative control consisting of cells transformed with an empty construct, which helps evaluate the effect of the (empty) vector on transformation (IITA researcher, pers. comm.). Thus, if the experimental outcome is not as expected, the negative control can deduce whether this was due to the transgene(s) in question or some other flaw in the experimental design (assuming all experimental parameters were kept identical/constant). However, the inclusion of the two latter types of controls was considered redundant for the purpose of this experiment, as the methods of transformation is part of an already established protocol.

Randomisation, edge and placement effects

Plants can respond to miniscule fluctuations in environmental/growth conditions, and placement and edge effects can in turn affect factors such as light levels, phototropism and geotropism; all of which may have an effect on the experimental outcome (Rufelt, 1961; Poorter *et al.*, 2012). Thus, ideally, the cultures should have been randomised at certain time intervals in the growth room. Furthermore, factors such as variable compositions of the medium (e.g. due to human errors when weighing compounds or adjusting pH), the distance in which ECSs are spread onto the nylon mesh, and level of moisture (e.g. from pouring plates while the medium is still hot) can cause some degree of variation that is not necessarily explained by e.g. cultivar or construct-dependent effects.

Other confounding factors

Finally, limited success during transformation can be due to, amongst others, (i) inadequate preparation of the embryogenic cells prior to transformation, e.g. the cells were heat shocked at suboptimal temperatures (i.e. lower or higher than 45-48˚C) and/or time (i.e. too short or longer than five minutes); (ii) inadequate preparation of the *Agrobacterium*, such as failed integration of the construct (however, the plasmid extraction and subsequent agarose gel analyses indicated that the bacterial cells had taken up the plasmid; Fig. 6.5 and Fig. 6.6); (iii) suboptimal concentration and/or quality of plasmid DNA used for transformation, as observed for some of the samples during the nanodrop reading (Table 6.3 and 6.4), though the quality and quantity was deemed sufficient for use in transformation (IITA researcher, pers. comm.); (vi) suboptimal concentration of *Agrobacterium* (however, optimal level was verified using OD_{600}); and/or (v) failure to balance the selective antibiotics (e.g. the concentration was inadequate in terms of killing off the *Agrobacterium* or, alternatively, killed off the plant cells).

6.2.3.4. Optimising the protocol

Unfortunately, cultivar-dependent challenges cannot be overcome by employing more virulent *Agrobacterium* strains (Hansen *et al*., 1994; Liu & Nester, 2006; Nyaboga *et al*., 2014) or more optimal conditions for regeneration and plant culturing (Lee *et al*., 2002; Zuo *et al*., 2002). Thus, the protocol has to be optimised for each cultivar (Tripathi *et al*., 2015), including optimations of the starting material (size, osmotic stage, etc.), the osmotic conditions of the medium, the concentration of plant growth regulators (e.g. auxins), and the physiological conditions, such as pH and temperature (Strosse *et al*., 2003; Tripathi, pers. comm.). Additionally, compounds which induce embryogenesis (e.g. certain amino acids and polyamine) and nurse (feeder) cultures (i.e. growth of cells on a contiguous culture of a different origin; Schaffer, 1990) can be employed (Strosse *et al*., 2003). Furthermore, an improved understanding of the underlying mechanisms and influential factors of (i) somatic embryogenesis (e.g. different physical and chemical treatments which negatively affects the quality of embryos), (ii) *Agrobacterium*-mediated transformation (e.g. which genes that stimulate division and growth of plant cells, control integration of T-DNA, and enhance competency of plant cells to *Agrobacterium*; Cheng *et al*., 2004), and (iii) somaclonal variation may positively contribute to increased transformation and regeneration efficiency. For instance, researchers are currently trying to identify factors responsible for somaclonal variation by detecting associated molecular markers (e.g. Abdellatif *et al*., 2012).

6.2.3.5. Alternative regeneration and transformation methods in banana

Other platforms for regeneration and transformation have been employed in banana, including the use of apical shoot tips and intercalary meristematic tissues, for which the latter facilitated a relatively rapid, efficient and cultivar-independent protocol (May *et al*., 1995; Tripathi *et al*., 2005, 2008). However, its practical use is severely hampered due to chimerism (Tripathi, pers. comm.). Thus, despite the laborious and time-consuming protocol of establishing embryogenic cell suspensions in banana, ECSs remain the explant of choice due to the single-cell origin of transformants which circumvents the issue of chimeras (Strosse *et al*., 2003; Roux, 2004). Furthermore, ECSs can be acquired from a range of tissues, including basal leaf sheats and corm section (Novak *et al*., 1989), immature female flowers (Grapin *et al*., 1998, 2000), and zygotic embryos (Marroquin *et al*., 1993). Still, immature male flowers and proliferating meristem cultures remain the most commonly used explant (Tripathi, pers. comm.).

Additionally, genetic transformation of Musa *spp*. has been achieved using micro-projectile bombardment of ECSs (Sági *et al*., 1995; Côte *et al*., 1996; Becker *et al*., 2000) and electroporation (Sági *et al*., 1995). Yet, *Agrobacterium*-mediated transformation is the preferred method due the advantages it offers (section 6.1.4).

6.2.3.6. Employing the techniques in other agronomical and economic important crop varieties

Similar techniques as those employed by Tripathi *et al*. (2015) for transformation of banana and plantain have already been, or could potentially be, applied to other crop species globally, including varieties of economical and agronomical importance to Africa and the East African region. For instance, embryogenic suspensions have been useful for obtaining transgenic calli via biolistic bombardment in rice (Fauquet *et al*., 1996). Somatic embryogenesis is the method of choice for transformation and regeneration in maize (González *et al*., 2012), and *Agrobacterium*-mediated transformation has successfully been achieved using explants such as immature embryos (Ishida *et al*., 2007). Sweet potato was long considered recalcitrant to somatic embryogenesis, but the protocol is continuously being improved using different explants and being adapted to different cultivars (e.g. Otani & Shimada, 1996; Al-Mazrooei *et al*., 1997; Liu *et al*., 1997; Dhir *et al*., 1998; Xing *et al*., 2008; Manrique *et al*., 2013), while a variety of explants can be transformed using *Agrobacterium* (e.g. Luo *et al*., 2006). In cassava, embryogenic suspension cultures is the platform of choice when employing *Agrobacterium*-mediated transformation, and somatic embryogenesis and plant regeneration have successfully been achieved in landraces from Cameroon (González *et al*., 1998; Bull *et al*., 2009; Chauhan *et al*., 2015; Mongomake *et al*., 2015). *Agrobacterium*-mediated transformation has also been successfully achieved in sorghum (using immature embryos) and yams (using axillary buds) (Nyaboga *et al*., 2014; Wu *et al*., 2014). For the latter, plant regeneration has also been achieved via somatic embryogenesis from callus cultures (Shu *et al*., 2005; Padrón *et al*., 2011).

6.2.4. Concluding remarks and outlooks

The practical work performed for the purpose of this thesis has demonstrated the methods developed by Tripathi *et al*. (2015) for the creation of transgenic banana and plantain (*Musa spp.*) using *Agrobacterium*-mediated transformation of embryogenic cells and recovery of transgenic lines via somatic embryogenesis. The GUS assay and subsequent PCR analysis verified the successful transformation of the cultivar 'Sukali Ndiizi' for the expression of the β-glucuronidase gene (*gusA*). Contrary, the stable GFP assay and PCR analysis performed for lines of 'Sukali Ndiizi' transformed with *gfp* indicated that the transfomation had been unsuccessful. In the case of 'Cavendish Williams', none of the embryos successfully regenerated into whole transgenic plantlets.

The laboratory work has provided insight into the advantages and limitations of using ECSs, somatic embryogenesis and *Agrobacterium* as platforms for regeneration and transformation. The establishment of ECSs is considered the major limiting factor for transforming Musa *spp.,* and the time and labour-intensive protocol, genotype-dependent effects, potentially high levels of somaclonal variation and risk of contamination makes it challenging to establish routine procedure for various cultivars and to meet the need for mass production (Strosse *et al*., 2003). Other explanatory factors for the failed transformation and regeneration of the present study include, but are not limited to, the age and quality of the embryogenic cells, inadequate preparation of the embryogenic cells or *Agrobacterium* prior to transformation, and suboptimal quality and quantity of plasmid DNA.

That being said, once a protocol has been optimised and established, hundreds of transgenic lines of genetically uniform plants with a single cell origin – thus circumventing the issue of chimeras -- can be obtained from cultivar-responsive embryogenic cell suspensions. Consequently, at the present time, *Agrobacterium*-mediated transformation of ECSs represents the most robust and high-throughput method for regeneration and transformation of *Musa spp.* Thus, the protocol holds great promise for developing improved varieties with agronomical important traits such as high yield, improved quality of fruit, reduced height, enhanced photosynthetic and nitrogen-use efficiency, and resistance to pest and diseases – including BXW, which currently represents the most important biotic constraint on the production of bananas in East and Central Africa (Pillay *et al*., 2002; Bakry *et al*., 2009; Tripathi *et al*., 2015).

Part C. Politics and the International GMO Debate

Chapter 7. Laws, Regulations and Policies Governing Biosafety and Biotechnology in East Africa

7.1. Introduction

7.1.1. What is biosafety?

There is no unified agreed definition of biosafety (Horna *et al*., 2013). However, biosafety often refers to all safety aspects associated with living or genetically modified organisms (LMOs and GMOs, respectively), and may entail measures, policies and procedures that minimise the potential risks that biotechnology may pose to humans, animals and the environment (including strategies for risk assessment, management, regulation, communication and mitigation) (CBD Secretariat & UNEP, 2003; Mtui, 2012; Horna *et al*., 2013;). For the purpose of this thesis, biosafety will be considered in terms of the use of GMOs in food and agriculture. In agriculture, the concept often involves reducing (i) the risk of spread of transgenic genes, (ii) impact on non-target organisms (e.g. competitiveness/invasiveness, and loss of biodiversity and ecosystem function), (iii) potential deleterious effects on human and animal health (e.g. toxicology and allergenicity); and (iv) socio-economic impacts (FAO, 1999).

7.1.2. Approaches to biosafety and biotechnology policies

Powerful and novel technologies often require governments to make new and unfamiliar policy choices (Paarlberg, 2001). Paarlberg (2001) categorised regulatory approaches according to whether biotechnology is considered inherently risky and consequently whether the regulations promote or prevent the use of biotech crops (Table 7.1). Such a categorisation also reflects the product/process debate, i.e. whether the regulatory approach is based on the process by which one obtains the transgenic organism/product or the end characteristics of the product (be it a living organism or products thereof) (Kuzma, 2016). However, governments may choose a variety of approaches depending on the issue in question, for instance whether it is concerning intellectual property rights, biosafety, trade, food safety and consumer choice, public research investment, and so forth (Paalberg, 2001).

Table 7.1. Approaches to biosafety policies associated with genetically modified (GM) crops and food technologies.				
	Promotional	**Permissive**	**Precautionary**	**Preventive**
Characteristics	Designed to accelerate the adoption of GM crops and food technologies	Neutral policies	Tend to slow the widespread adoption of GM crops, but without a complete ban of the technology	Attempt to ban the technology completely
Risk assessment and approval process	No screening, or approval based on approval in other countries	Case-by-case screening for demonstrated risk, based on intended use of product	Case-by-case screening for scientific uncertainties as well as demonstrated risks, owing to the novelty of the GM process	No careful case-by-case screening; biosafety risk assumed because of the process of genetic modification
Table adopted from Paalberg (2001).				

Strict regulations and stringent provisions may be highly efficient at minimising potential risks, but may also work to substantially inhibit R&D by imposing high costs on developers, which may be particularly devastating in countries with limited resources (Meijer & Stewart, 2004). Contrary, if the regulatory system is too relaxed, it might fail to protect society and the environment from potential impacts (FAO, 2003). Thus, a sound legal framework is not only important for the safe delivery of approved technologies, but is also a way of building trust between governments and the public by ensuring that the technology works in the public's best interest (Chambers *et al*., 2014).

7.2. External influences on the development of biosafety regulations and policies in East Africa

The development of biosafety and biotechnology regulatory frameworks in East Africa has been influenced – directly and/or indirectly – by international, intracontinental and sub-regional laws, protocols, initiatives and organisations. Of particular importance is the Cartagena Protocol of Biosafety and the precautionary principle, the African Union's Model Law on Safety in Biotechnology, and various capacity building initiatives and donor agencies (e.g. UNEP-GEF and PBS). Furthermore, other factors such as historical ties with the technology (e.g. early practical experience), relationships with Great Powers (Chapter 8) and NGO lobbying (Chapter 9) have affected the perceptions and approaches to biosafety and biotechnology.

7.2.2. The Convention on Biological Diversity (CBD) and the Cartagena Protocol on Biosafety (CPB)

The International Convention on Biological Diversity (CBD) was established in 1993 and was among the first international consortiums to recognise the need for a biosafety system (United Nations, 1992a; CBD Secretariat, s.a.-a, s.a.-b.). The Cartagena Protocol on Biosafety (CPB) under the CBD was drafted in the year 2000, and is a legally binding protocol whereby the main objective is to "contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms (LMO) resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements” (CBD Secretariat, 2000). In other words, the protocol is meant to facilitate safe transnational transfer of LMOs, and require members to – amongst other – develop a functional National Biosafety Framework (NBF). The key components of a NBF includes (i) policies on biotechnology; (ii) biosafety laws and regulations (including a regulatory regime for biotechnology); (iii) an administrative system for dealing with applications and permits; and (iv) a way of engaging the public in biosafety decision-making (Makinde *et al*., 2009).

The CPB has been signed and ratified by Kenya, Uganda, Ethiopia and Tanzania (CBD Secretariat, 2017), and thus has provided a blueprint for the development of the NBFs in all study countries – with variable degree of success (Table 7.2) (Makinde *et al*., 2009; Mtui, 2012; Chambers, 2013). However, the implementation of the CPB in many African countries, such as Tanzania and Ethiopia, has been deemed premature by some, as it was introduced at a point where the countries lacked practical experience with agricultural biotechnology (Chambers, 2013).

7.2.3. The Precautionary Principle

Several definitions of the precautionary principle exist, including that of the Rio Conference of 1992 and the CPB (United Nations, 1992b; CBD Secretariat, 2000). However, the definitions all touch upon the same matter – if there is reason to believe that an action or a policy may cause serious or irreversible threats to humans or the ecosystem, then “acknowledged scientific uncertainty should not be used as a reason to postpone preventive measures” (WHO, 2004; Myhr, 2007). Put in the context of GM crops, the approval of a new biotech crop variety can be withheld when there is no clear evidence of safety (Adenle, 2011). The precautionary principle is embraced by the CPB, as well as the regulatory approaches assumed by several EU Member States, and as a result has been a major influential factor of regulatory decision-making in many African countries (Chambers *et al*., 2014).

However, the precautionary approach has been criticised on several grounds, including (i) being too risk-averse and inconsistent with the standards of evidence-based decision-making; (ii) lacking clear guidelines on when the precautionary principle can be set aside by evidence of safe usage; (iii) not properly considering the potential benefits that the technology may offer to the poor; (iv) containing strict articles related to liability and redress (for instance, if a product is perceived as defective or harmful, any entity or person that participated in the production process — e.g. the developer, the manufacturer, the wholesaler and/or the retailer – can be held accountable, which is in stark contrast to a fault-based regulatory system in which responsibility and corrective measures are applied to an accountable and offending party, respectively); and (v) lacking social, ethical and economic considerations of GMO adoption (Macilwain, 2000; WHO, 2004; Chambers, 2013; Atkinson *et al*., 2015). As a consequence, the precautionary principle has been the topic of many heated debates between pro and anti-GMO countries and advocates (Macilwain, 2000; WHO, 2004).

7.2.4. The African Model Law on Safety in Biotechnology (AU Model Law)

Concurrently with the CPB negotiations, the Model Law on Safety in Biotechnology (from now on referred to as the AU Model Law) was developed during a workshop in Addis Ababa in 1999 (Chambers, 2013; Godfrey, 2013), and was adopted by the African Union in 2001 (African Union, 2001). Member States – which include all the study countries – are urged to employ the Law when drafting their national biosafety legislations (Chambers, 2013). The Model Law was reviewed in

2006/2007, upon which the following main objectives were stated: "(i) to contribute to ensuring an adequate level of safety for the protection of biological diversity, human and animal health, socio-economic conditions and ethical values in the making safe transfer, handling and use of genetically modified organisms and products of genetically modified organisms resulting from modern biotechnology; (ii) to enable countries that are members of the Cartagena Protocol on Biosafety to implement the provisions of the Protocol at the national level" (African Union, 2007; Godfrey, 2013; Kongolo, 2013).

Though the Model Law has contributed to increased awareness of biosafety, it has been criticised for being an extreme interpretation of the CPB and the precautionary principle, as well as putting too much emphasis on socio-economic considerations (see Part D and Chapter 23 in particular) (Chambers, 2013; Godfrey, 2013). That being said, governments tend to interpret and apply the AU Model Law differently – the Law has affected most elements of the Tanzanian regulatory system, while it only applies to certain aspects of the Kenyan and Ugandan regulations. For instance, the precautionary principle has been somewhat moderated in the latter two countries, and Kenya has opted for a fault-based approach to liability and redress (Mtui, 2013; Chambers, 2013). This difference in interpretation is believed to put constraints on trade and commerce (Chambers, 2013).

7.2.5. Other external influences: The World Trade Organization (WTO), the Food and Agricultural Organization (FAO), the Codex Alimentarius, and the World Bank

World Trade Organization (WTO) and Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement

Kenya, Uganda and Tanzania are all members of the World Trade Organization (WTO), while Ethiopia remain a so-called "observer" (an "observer" must start accession negotiations within five years) (WTO, s.a.-a). The main orientation of the WTO is free trade in conjunction with environmental, health and regulatory policies of its members (Meijer & Stewart, 2004). However, consensus is required for each new agreement, which constrain the legislative abilities and authority of the WTO. Thus, the organisation has yet to establish clear guidelines on the conditions in which countries can restrict trade of GMOs and GM products (Meijer & Stewart, 2004; WTO, s.a.-b).

The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the WTO requires all Member States to establish a minimum standard of legal protection and enforcement of Intellectual Property Rights (IPRs) (Dutfield, 2001; WTO, 2015). The Agreement makes patents available for most technological inventions, including plant varieties, but does not require its members to use such patents (WTO, 2001; Chambers *et al*., 2014). As Member States of the WTO, Kenya, Uganda and Tanzania are all required to comply with the TRIPS agreement (note that countries defined as least developed – which includes Uganda, Tanzania and Ethiopia – have been given an extension until 2021; WTO, 2013). The TRIPS agreement has been the subject to many debates associated with GMOs, Farmers' Rights and other socio-economic considerations, which is further explored in the Chapter 13.

The Food and Agriculture Organization (FAO)

The Food and Agriculture Organization (FAO) supports agricultural development in developing countries by promoting international standard-setting bodies (e.g. the Codex Alimentarius; see below), providing technical, regulatory, and management capacity building, and distributing information and raising awareness (FAO, 2000). FAO assumes a relatively pro-GMO stand and has made several statements in favour of biotech crops as a mean of benefiting the poor (FAO, 2004a).

Codex Alimentarius

The Codex Alimentarius, also known as the Food Code, was developed by FAO and the World Health Organization (WHO) in 1963 (Codex Alimentarius, 2016a). The Codex consists of an open forum where governmental officials and experts discuss food regulations, and is meant to serve as a reference point for governments when "formulating national policies and plans with regards to food […], as far as possible adopt standards from the Codex Alimentarius" (Codex Alimentarius, 2016b). However, the success of the Codex has been limited to certain aspects, including risk analysis of GM plants and foods, while no consensus has been reached in terms of, for instance, guidelines and recommendations for labelling or risk management (Meijer & Stewart, 2004; Codex Alimentarius, 2016c).

The World Bank and the Consultative Group on International Agriculture Research (CGIAR)

In the 1970s, the World Bank created the Consultative Group on International Agriculture Research (CGIAR) to which most international agricultural research centres (IARCs) belong, including the International Institute of Tropical Agriculture (IITA) (Meijer & Stewart, 2004). The aim of CGIAR is to preserve and improve genetic resources for agriculture in developing countries by creating new and improved crop varieties (both conventional and transgenic), as well as to increase capacity building by training local scientist (Meijer & Stewart, 2004; CGIAR, 2006, s.a.). Though the CGIAR main efforts are within the field of R&D, the group has acknowledged the need for effective technical and regulatory capacities in order to deal with the potential ecological risks of biotech crops (Meijer & Stewart, 2004). Thus, the World Bank has also formed an Agri-Biotechnology Task Force and a Rural Development Strategy with the goal of assisting countries in the assessment and safe use of new technologies by financing capacity building initiatives (World Bank, 2003). Whereby the World Bank is not as outspoken in regards to its stance on GMOs, the CGIAR appear more positively inclined and vocal on the matter (Meijer & Stewart, 2004).

7.2.6. Regulatory capacity building initiatives: UNEP-GEF, ABNE, PBS and BIO-EARN

The United Nations Environment Programme-Global Environment Facility (UNEP-GEF)

UNEP-GEF was one of the first biosafety capacity building programs in Africa and was initiated in Kenya and Uganda in 1997, in Ethiopia in 2002 and in Tanzania in 2003 (UNEP, s.a.-b; CBD Secretariat, 2012). UNEP-GEF assists countries in developing their NBFs (UNEP, s.a.-a; Chambers, 2013), but the progress has at times been slow or even stagnant (Makinde *et al*., 2009). Furthermore, the program has been criticised for establishing a range of regulatory requirements that has caused considerable delays and created a window of opportunity for anti-GMO activists (see Chapter 9) (Paarlberg, 2014). Paarlberg (2014) argues that this is partly the reason why 21 out of 23 African countries have adopted the most restrictive "Level One" approach to biosafety (UNEP, 2006), which might have further prevented the commercialisation of most GM crops meant for food and feed (Paarlberg, 2014).

African Biosafety Network of Expertise (ABNE)

In 2008, the African Biosciences Initiative (ABI) of the New Partnership for Africa's Development (NEPAD) established the African Biosafety Network of Expertise (ABNE) in collaboration with Michigan State University and with support from the Bill and Melinda Gates Foundation (Makinde *et al.*, 2009; NEPAD, s.a.-b). ABNE aims to aid in the development of functional regulatory systems in a way which maximises the benefits, while minimising the potential risks of agricultural biotechnology (NEPAD, s.a.-b). Importantly, ABNE is for Africans, by Africans, which is believed to be important for establishing credibility between African governments and the public (Makinde *et al.*, 2009).

The Program for Biosafety Systems (PBS)

The Program for Biosafety Systems (PBS) is managed by the International Food Policy Research Institute (IFPRI) and is funded by USAID (Program for Biosafety, s.a.). It is among the oldest biosafety capacity building programs still active in Africa, and the program has been particularly engaged in Kenya, Uganda and Tanzania (Chambers, 2013). PBS, together with ABNE, assumes a more science-based and liberal approach to GM crops and has played an important role in the creation of the early operational frameworks and field trials in Kenya and Uganda (Chambers, 2013). For instance, it is believed that PBS helped coordinate legal reviews, as well as promoting outreach, education of and communication with stakeholders, which ultimately lead to the passage of the Kenyan National Biosafety Act of 2009 (Program for Biosafety, s.a.). The reasons why PBS has not had the same level of impact in countries such as Ethiopia has not yet been identified, but could perhaps be explained by lack of practical history and capacity within agricultural biotechnology.

The Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN)

The Eastern Africa Regional Program and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development (BIO-EARN) was established in 1998 with aid from the Swedish International Development Cooperation Agency (Sida) (Forsman *et al.*, 2011; Chambers *et al.*, 2014). The overall aim is to improve human and infrastructural research and regulatory capacity, and the initiative has done so in all study countries (Chambers *et al.*, 2014). Furthermore, the program has assisted in the exchange of information on regulatory practices and policy issues in the region (Chambers *et al.*, 2014). Additionally, BIO-EARN has contributed to the development of new and improved varieties of, amongst others, sorghum, cassava and sweet potato (Chambers *et al.*, 2014).

7.3. Agricultural biotechnology in Kenya, Uganda, Tanzania and Ethiopia: Laws, regulations and the political climate

In the East African region, Kenya, Tanzania and Ethiopia have enacted laws governing biosafety and/or biotechnology, while Uganda has yet to pass its Biotechnology and Biosafety Bill into law (Fig. 7.1).

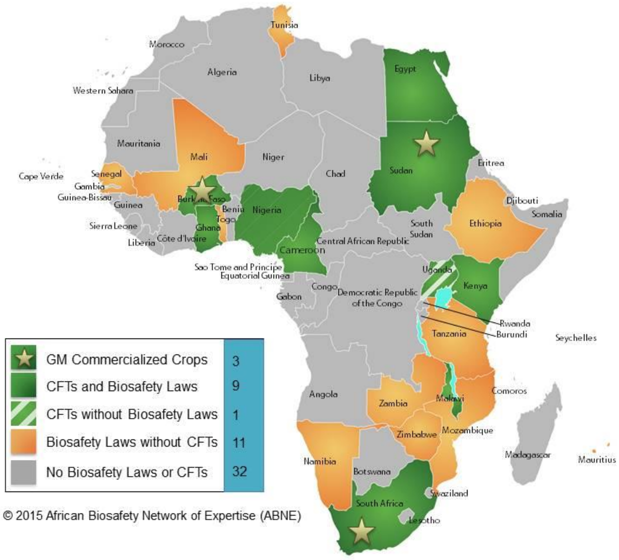


Figure 7.1. African countries that allow for commercialisation of genetically modified (GM) crops (indicated by a star) or confined field trials (CFTs), with or without biosafety laws in place (green or green striped, respectively). Some countries have biosafety laws in place, but are not carrying out field trials (orange), while others lack both (grey). Note that since this figure was produced, Burkina Faso has temporarily halted its cultivation of GM crops, while Tanzania, Ethiopia, Mozambique and Swaziland have started carrying out CFTs. Figure from: ABNE, 2015.

7.3.1. Kenya

7.3.1.1. Historical ties to agricultural biotechnology

After its independence from Britain in 1963, Kenya inherited a relatively strong agricultural research infrastructure and has since then continued to carry out R&D within biotechnology and genetic transformation (Harsh, 2005; Cooke & Downie, 2010). In 1991, Kenya became the first African country to establish a public-private partnership (PPP) between the Monsanto Company and KALRO (then known as KARI) for the creation of virus-resistant sweet potatoes (Chambers, 2013). The PPP was considered a landmark activity which sparked further capacity building in the country (though the project itself has been labelled a failure by some; Ching, 2004; IATP, 2004; New Scientist, 2004) (Chambers, 2013). As a result, Kenya has been recognised as a biotechnology “role model” in East Africa and the Sub-Saharan as a whole (Harsh, 2005).

7.3.1.2. The development of the Kenyan regulatory framework and policy

The lead science authority in Kenya, the National Council for Science and Technology (NCST), was established in 1980 as a result of the Science and Technology Act (Republic of Kenya, 2009a). Between 1995 and 1998, the NCST founded the National Biosafety Committee (NBC) that would be responsible for issuing biosafety guidelines and regulations (Chambers, 2013; Harsh 2005).

However, the original regulatory system had certain limitations associated with the legal enforcement authority of the NBC, as well as lacking provisions concerning commercialisation and procedures related to import, export and transit (Chambers, 2013). In order to correct the deficiencies of the old system, the National Biotechnology Development Policy was approved in 2006 and was considered a "go-ahead" for the use of biotechnology in the country; it stated that "the government has identified biotechnology as an appropriate tool and vehicle that can deliver economic gains through intellectual property creation to expand entrepreneurial opportunities for industrial growth, reduction of poverty, and improvement of food security, health, and environmental sustainability" (Ogodo, 2006; Republic of Kenya, 2006; Chambers, 2013).

The National Biosafety Act was enacted in 2009 (Republic of Kenya, 2009b), and was considered one of the most liberal and facilitating biosafety and biotechnology laws in Africa (Cooke & Downie, 2010). It resulted in the establishment of the National Biosafety Authority (NBA) in 2010. In 2011 and 2012, the NBA published regulations concerning contained use (Republic of Kenya, 2011a), import, export and transit (Republic of Kenya, 2011b), environmental release (Republic of Kenya, 2011c), and labelling (Republic of Kenya, 2012).

Findings from the Stakeholder perception survey: Awareness and opinions of the Kenyan National Biosafety Act

Awareness of the Act. 89.7% of stakeholders were aware of the Kenyan Biosafety Act of 2009, while 9.0% were unaware (1.3% did not reply; not shown in Fig. 7.2) (Fig. 7.2). There were significant differences in the level of awareness of the Act on the basis of nationality (Appendices 1, Table E.4). Of those aware, 49 were Kenyan (70%), nine were Ugandan (~13%), eight were Ethiopian (~11%) and four were Tanzanian (~6%) (Fig. 7.2). Of those unaware of the Act, five were Tanzanian (~71%) and two were Ugandan (~29%) (Fig. 7.2). One respondent (Ethiopian) left the question blank (not shown in Fig. 7.2).

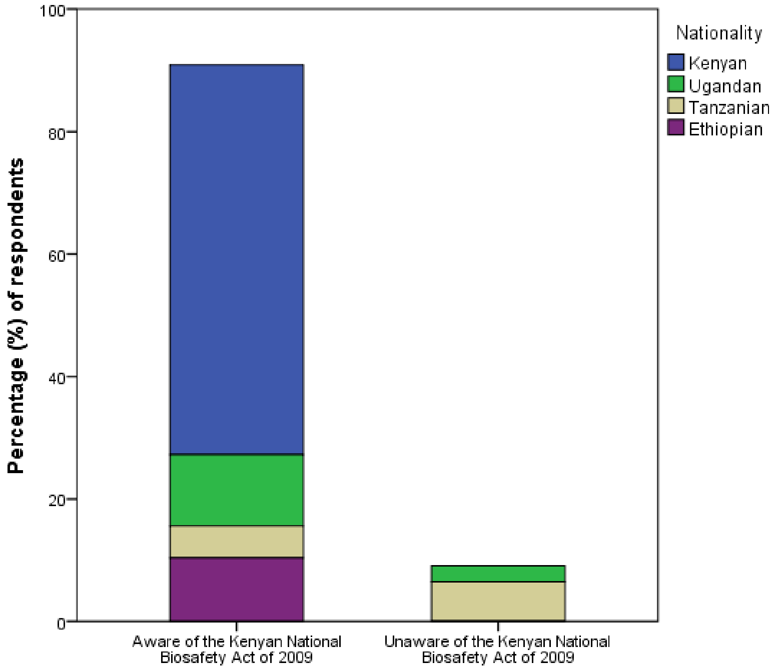


Figure 7.2. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that was aware of the Kenyan National Biosafety Act of 2009. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the level of awareness on the basis of nationality ($p<0.001$). Response rate: ~99% (77 out of 78 participants).

Thus, all of the Kenyan and Ethiopian stakeholders were aware of the Act, while Tanzania was the only nationality for which the majority of stakeholders were unaware. However, this was only a matter of a single respondent, which is unlikely to explain the observed significant effect.

Perceptions of the Act. 74.4% of stakeholders perceived the National Biosafety Act as "wise and timely", 15.4% found the Act "unwise and untimely", while 10.3% reported "other viewpoints" (for instance, one stakeholder perceived the Act as having been modelled on the South African law, which was considered too permissive by the participant; others believed that the Act was not in the best interest of Kenya and that the information that had led to its approval had been biased) (Fig.7.3)

There were no significant differences in the opinions of the Act on the basis of nationality (Appendices 1, Table E.4). Of those that perceived the Act as "wise and timely", 40 were Kenyan (~69%), six were Ugandan (~10%), six were Tanzanian (~10%) and six were Ethiopian (~10%) (Fig. 7.3) (Fig. 7.3). Of the stakeholders that perceived it as "unwise and "untimely", eight were Kenyan (~67%), two were Ugandan (~17%), one was Tanzanian (~8%) and one was Ethiopian (~8%) (Fig. 7.3). Finally, of those that expressed "other viewpoints", three were Ugandan (37.5%), two were Tanzanian (25%), two were Ethiopian (25%) and one was Kenyan (12.5%) (Fig. 7.3).

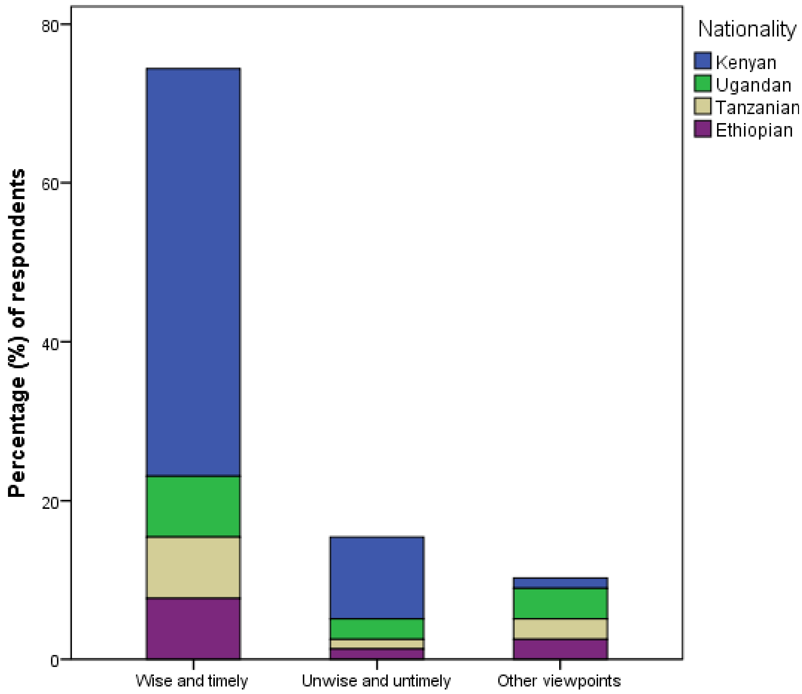


Figure 7.3. Opinions of the Kenyan National Biosafety Act of 2009 among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were no significant (NS) differences in the opinions of the Act on the basis of nationality ($p>0.05$). Response rate: 100% (78 out of 78 participants).

However, there were significant differences in the opinions of the Act on the basis of the respondents' general attitude towards GM crops (i.e. perception group, PG) and occupation (Appendices 1, Table E.4). 80% and ~91% of respondents from PG3 and PG4 perceived the Act as "wise and timely", while none of the civil servants employed in the public/private sector related to agriculture or agricultural researchers considered the Act "unwise and untimely" (Appendices 1, Table E.5.1). The majority of participants from PG1 (~56%) found the Act "unwise and untimely", while civil servants from NGOs divided themselves relatively equally between "wise and timely" and "unwise and untimely" (Appendices 1, Table E.5.1). Additionally, there were weakly significant differences in the way in which the Act was perceived on the basis of the participants' cultural leaning (Appendices 1, Table E.4). None of those that categorised themselves as liberal considered the Act "unwise and untimely", while ~69% of stakeholders that were culturally moderate shared the same opinion (Appendices 1, Table E.5.1).

Leading on from this, 79.5% of stakeholders believed that the Act would inspire other African countries to follow suit, while 14.1% of respondents did not believe this to be true (Fig. 7.4). There were weakly significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that believed the Act would inspire other African countries, 44 were Kenyan (~71%), eight were Ugandan (~13%), seven were Ethiopian (~11%) and three were Tanzanian (~5%) (Fig. 7.4). Of those that were of the opposite opinion, five were Kenyan (~45%), three were Ugandan (~27%) and three were Tanzanian (~27) (Fig. 7.4). Five respondents did not reply to the question, of which three were Tanzanian (60%) and two were Ethiopian (40%) (Fig. 7.4).

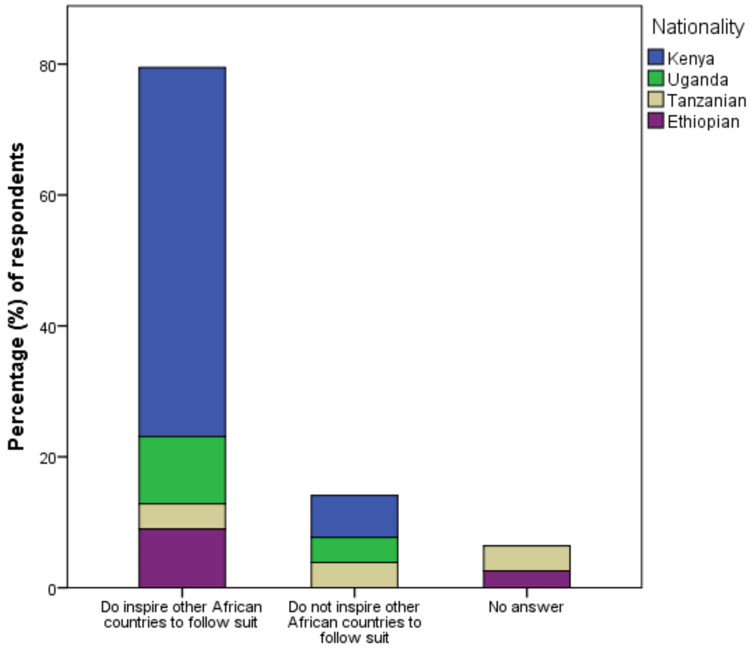


Figure 7.4. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that believed the Kenyan Biosafety Act of 2009 would inspire other African countries to follow suit. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions expressed by stakeholders on the basis of nationality ($p<0.05$). Response rate: ~94% (73 out of 78 respondents).

Thus, all of the Ethiopian stakeholders (with the excpetion of the two that did not respond), and the majority of Kenyan (~90%) and Ugandan (~73%), believed the Act would inspire other African countries to follow suit, while Tanzanian stakeholders divided themselves equally across response categories.

Additionally, there were significant differences in the opinions of whether the Act would inspire other African countries to follow suit on the basis of perception group and age (Appendices 1, Table E.4). The majority of participants from all perception groups believed the Act would inspire other African countries, especially respondents from PG4 (~94%) (Appendices 1, Fig. E.5.2a). However, respondents from PG1 represented over half (~55%) of those that did not find this to be true (Appendices 1, Fig. E.5.2a). In terms of age, all of those aged 40-49 and 60-79, and the majority of those aged 30-39 and 50-59, believed the Act would inspire other African countries. Half (50%) of those aged 19-29 were of the opposite opinion, though one third of this age group did not respond (Appendices 1, Fig. E.5.2b).

7.3.1.3. Political will in recent years
A strong political will to further develop the agricultural biotechnology sector in Kenya is evident from the works of former presidents, including the opening of KARI/KALRO and BecA-ILRI, and announcements made by several governmental representatives in support of biotechnology (Mtui, 2012; Chambers, 2013). For instance, in 2016, the Kenyan Cabinet Secretary for Ministry of Agriculture, Livestock and Fisheries stated that the only way for Kenya to increase food production was through means of modern technologies, including GM crops (ISAAA, 2016e). However, there has been increased political interference in latter years, which is thought to reflect recent elections and heightened activity by anti-GMO groups (Chambers, 2013). Indeed, the conflicting attitudes of policymakers and governmental officials make it difficult to navigate the current political climate sorrounding biotech crops, whereby the current ban on the importation of GM crops and products thereof is a prominent example.

The 2012 ban on the importation of GM seeds and commodities
The 2012 ban on the import of GM crops, planting material and commodities signals an apprehensive attiude towards biotechnology and is considered a major obstacle for the adoption of GM crops (Paarlberg, 2001; Snipes & Kamau, 2012). As Kenya has assumed somewhat of a leadership role, the ban may have contributed to slowing down development in the entire East African region. Furthermore, the ban has affected importation of emergency food aid, excluded major export partners such as South Africa, negatively influenced the uptake of students to biotechnological courses, and discorauged foreign investors (Komen & Wafula, 2013; Chao-Blasto, 2014; OFAB, 2016; Nguthi and Oduor, pers. comm.).

According to Dr. Faith Nguthi and Dr. Richard Okoth Oduor, the ban was instituted by the cabinet at a time when cancer cases had gained prominence, and the publication of the paper by Séralini *et al*. (2012) which linked GM food products to cancer (section 5.2) made matters worse (Willingham, 2012). An immediate ban followed without any prior investigation into the report and without consulting the NBA. “The GMO debate was already present in Kenya [before the Séralini-article was published], but this was just what the anti-GMO movement needed to ‘put the nail in the coffin’”, said Dr. Oduor.

Even after the Séralini-article was retracted – and the International Service for the Acquisition of Agri-biotech Applications (ISAAA) through the Open Forum on Agricultural Biotechnology (OFAB) delivered an easy-to-grasp explanation of the article to the government (Nguhti, pers. comm.) – the ban still stood ground, even after the Deputy President, H.E. William Ruto, and the chief executive of the NBA, Dr. Willy Tunoi, stated that the ban would be lifted within a matter a months (James, 2015; OFAB, 2016).

Dr. Oduor sheds some light on the situation: “Firstly, with a coalition government, everything that the Deputy President declares will not necessarily go; the colation do not want to grant the Deputy the power to make executive orders. Secondly, with the upcoming election [taking place in 2017], the politicians might be apprehensive about lifting the ban as it might upset voters. However, if the ban was tweaked as a political tool to gain voters – especially the youth who are losing jobs as a result of the ban – then politician may be willing to ‘get their hands dirty’. Still, this would require the politicians to determine which sides has the more votes – the anti or the pro-GMO?”. Dr. Defegu also believed that the prospect of losing voters could make East African governments tread more carefully when addressing issues related to biotech crops. Finally, other forces may be at play, including the business aspect of such a ban: “A ban is an excellent way in which local producers can gain priority in the market and exclude foreign imports, which might be particularly true in the case of the maize business”, Dr. Okoth explained.

Certain farmer groups have supported lifting of the ban (ISAAA, 2015c), including a group of cotton farmers who expressed their concern about the devastating effect that pest and diseases have had on the once-so-vibrant cotton sector (ISAAA, 2015d). Additionally, farmers from Kirinyaga County urged the government to lift the ban on GM food import, as well as to hurry the release of WEMA-Bt maize, in response to the devastating drought that has caused failure of maize crops due to inadequate October-December short rains (ISAAA, 2017a). Contrary, the Kenya Small Scale Farmers Forum – which promotes the slogan “Our World is Not for Sale” – has threatened to sue the Kenyan government if the ban on GM imports was to be lifted, arguing that doing so would undermine indigenous crops and farmers’ and public rights (Sustainable Pulse, 2015).

Findings from the Stakeholder perception survey: Opinions of lifting of the Kenyan ban on GM crops and products thereof

61.5% of the stakeholders supported lifting of the Kenyan ban on GM imports, while 29.5% did not (9% of stakeholders did not respond) (Fig. 7.5). There were no significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that supported lifting of the ban, 34 were Kenyan (~71%), six were Ugandan (~13%), five were Ethiopian (~10%) and three were Tanzanian (~6) (Fig. 7.5). Of those that did not support lifting of the ban, 14 were Kenyan (~61%), four were Ugandan (~17%), three were Tanzanian (~13%) and two were Ethiopian (~9%) (Fig. 7.5). Seven respondents did not reply to the question, of which three were Tanzanian (~43%), two were Ethiopian (~29%), one was Kenyan (~14%) and one was Ugandan (~14%) (Fig. 7.5).

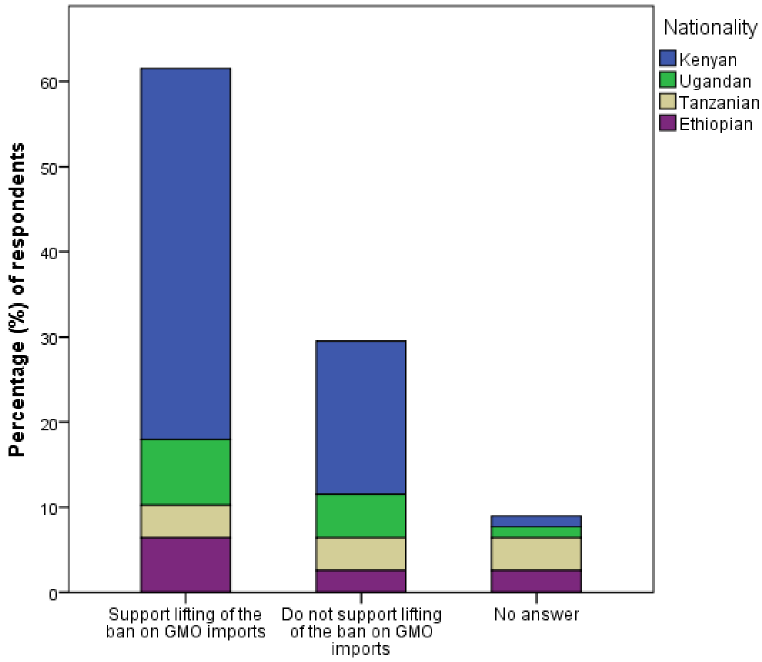


Figure 7.5. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported lifting of the 2012 Kenyan ban on the importation of genetically modified organisms (GMOs). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the opinions expressed by stakeholders on the basis of nationality (p>0.05). Response rate: ~91% (71 out of 78 participants).

However, there were significant differences in stakeholder opinions on the basis of perception group, occupation and educational level (Appendices 1, Table E.4). For the former, 65% and ~77 % of those from PG3 and PG4 supported lifting of the ban, while ~67% of respondents from PG1 were opposed (Appendices 1, Table E.1). Additionally, 87.5% of extension workers, ~71% of agricultural researchers and ~67% of civil servants in the public/private sector related to agriculture were in favour of lifting the ban (Appendices 1, Table E.1). The majority (~59%) of civil servants employed in a non-governmental organisation were not in favour of lifting the ban. In terms of education level, all of those with PhDs (except for one respondent that did not reply) and ~75 % of those with Bachelor degrees supported lifting of the ban (Appendices 1, Fig. E.5.3). Stakeholders of most other educational levels divided themselves relatively equally across response categories, though a slight majority (~56%) of those with some college did not support lifting of then ban (Appendices 1, Fig. E.5.3).

Of those opposed to lifting of the ban, some argued that there was insufficient scientific proof for the safety of GM crops and that studies failed to demonstrate the positive contribution of the technology to food and nutritional security. Others believed that lifting the ban would compromise local food production, freedom of trade and the economy as a whole.

7.3.1.4. Approval of environmental release: Steps towards commercialisation?

In 2015, the NBA received for the very first time two applications for environmental release (i.e. open field cultivation), namely of Bt-maize under the WEMA project (submitted by KALRO and AATF) and Bt cotton (submitted by Monsanto Kenya Ltd) (James, 2015). After considering food & feed safety, environmental assessments, certain socio-economic considerations (Appendices 3, Appendix A) and public comments, the NBA granted a conditional approval for the purpose of carrying out National Performance Trials (NPTs) (National Biosafety Authority, 2016a, b). The approval made Kenya the first East African country to have employed its own national biosafety law to allow environmental release of a biotech crop variety (ISAAA, 2016a).

Before the NPT can be initiated, an approval must be given by the National Environmental Management Authority (Nema) (part of the NBA), i.e. the authority responsible for managing environmental policies, including implementing and approving the environmental impact assessment (EIA) (Nema, s.a.). The field trials of the NPT are carried out by the Kenya Plant Health Inspectorate Service (Kephis) which is also part of the NBA. After the NPT is successfully completed – which is a process considered to take 2-3 years – an application for approval of planting and commercialisation can be submitted (National Biosafety Authority, 2016a).

However, following the approval of the NPT for GM maize, Nema informed KALRO and AATF that the NPT needed authorisation from the Ministry of Agriculture. The department on the other hand, told Nema that the Ministry did not exhibit the capacity to give policy directions (Andae, 2016a). Furthermore, in October of 2016, Nema denied ever granting the approval for Bt maize, which appeared to contradict what was stated on authority's website (Ngotho, 2016a). Furthermore, the health secretary Dr. Cleopa Mailu announced in a letter to the Ministry of Environment that the environmental release would be rejected as it is bound by the 2012 ban (Andae, 2016b).

Consequently, a state of limbo arose which is likely to delay commercialisation until after 2018, which was the target year of AATF (Andae, 2016c). Though Dr. Oduor remained positive that the approval marked a significant step in the direction of commercialisation – and that the first commercialised event will hit the East African market in a few years' time – he also expressed his frustration with the overall process.

7.3.2. Uganda

7.3.2.1. The development of the Ugandan regulatory framework and policy

The development of the NBF in Uganda was initiated between 1997 and 1998 by the Uganda National Council for Science and Technology (UNCST) (Sengooba *et al*., 2005; Mtui, 2012), and was adopted by the Ministry of Environment in 2001 (UCST, 2000). The focal point of the Biosafety Protocol was established within the Ministry of Environment, while UNCST under the Ministry of Finance constitutes the competent authority (i.e. responsible for issuing permits for applications of R&D, commercialisation, etc.) (Mtui, 2012; Chambers, 2013).

Despite being ratified in 2001, the Biosafety Protocol containing guidelines for containment, research, confined field trials, and so forth was not released until 2006 (Mtui, 2012; Chambers, 2013). In 2008, the National Biotechnology and Biosafety Policy was endorsed and approved by the Cabinet (Republic of Uganda, 2008), which led to the development of the draft Biotechnology and

Biosafety Bill (2012) (Republic of Uganda, 2012). The bill has yet to be passed into law, thus an interim regulatory system is currently instated (Mtui, 2012). However, despite this – or perhaps because of this – Uganda has become very attractive for foreign investors and biotech projects wishing to carry out research and field trials, which has promoted the country to a regional leader within agricultural biotechnology in recent years, perhaps more so than Kenya in some respects.

7.3.2.2. Political will and the passage of the Biotechnology and Biosafety Bill into law

Prior to 2008, there was strong political support in favour of biotechnology (Chambers, 2013; Chambers *et al*., 2014). However, the lack of a well organised coalition caused the development of the Biotechnology and Biosafety Bill to stagnate between 2008 and 2010 (a situation which is somewhat comparable to what is currently observed in Kenya in relation to the ban on GM imports) (Chambers, 2013). Consequently, in an attempt to unify stakeholders, the Uganda Biotechnology and Biosafety Consortium (UBBC) was formed in 2011, which is believed to have resulted in a more steady progress (Chambers, 2013). Still, the passage of the bill has been delayed and is supposed to be up for discussion again in the near future (ISAAA, 2016a).

Though opinions appear divided on the matter of the passage of the bill into law, it is gaining support from certain societal and governmental forces. For instance, President Yoweri Kaguta Museveni and MP Hon. Jackson Mbaju both called upon parliament to pass the bill so that farmers could gain access to biotech crops (ISAAA, 2016f; ISAAA, 2017b). The statement was embraced by the ruling political organisation in Uganda, the National Resistance Movement, as well as the Vice President Hon. Edwards Sekandi who referred to results obtained in countries such as Burkina Faso, Brazil and Argentina (see Chapter 16) (ISAAA, 2015e).

When Uganda Biosciences Information Centre (UBIC) hosted a debate on the passage of the National Biotechnology and Biosafety Law at the Makerere University, most attendees agreed that the law would work in the best interest of the Ugandan people, while those opposed argued that farmer concerns were not heard and asked for further revision of the bill (ISAAA, 2016i). Following the debate, a group of alumni and biotechnology students at the university voiced their support of the passage of the bill, stating that the delay was compromising R&D (Makerere University Biotechnology Students Association, 2016).

Certain farmer groups have also supported GM crops, including a group of potato farmers from Southwestern Uganda who urged their local leaders and the Members of Parliament to support the passage of the bill into law (ISAAA, 2016j). Contrary, in 2014, a demonstration against GMOs led by over 600 farmers from the Mount Elgon region raised concerns about health issues like obesity and impotence and farmers' livelihoods (Fig. 7.6). They further stated that the passage of the bill would cost members of parliament their votes, which underlines the impact that the GMO debate may have on election outcomes (Wambede, 2014).

Figure 7.6. Demonstration against genetically modified organsism (GMOs) and the passage of the Biotechnology and Biosafety Bill into Law by Ugandan farmers in Mbale Town (Mount Elgon region). Photo by Denis Mukungu. Figure from: Wambede, 2014.

Findings from the Stakeholder perception survey: Opinions of the passage of the Ugandan Biotechnology and Biosafety Bill into Law

73.1% of stakeholders supported the passage of the Biotechnology and Biosafety Bill into law, 20.5% did not support the passage, while 1.3% did not have an opinion (5.1% did not respond) (Fig. 7.7). There were no significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that supported the passage, 39 were Kenyan (~68%), seven were Ugandan (~12%), six were Ethiopian (~11%) and five were Tanzanian (~9%) (Fig. 7.7). Of the stakeholders that did were opposed, nine were Kenyan (~56%), four were Ugandan (25%), three were Tanzanian (~13%) and one was Ethiopian (~6%) (Fig. 7.7). One respondent (Kenyan) did not have an opinion, while four participants did not reply, of which two were Tanzanian (50%) and two were Ethiopian (50%) (Fig. 7.7).

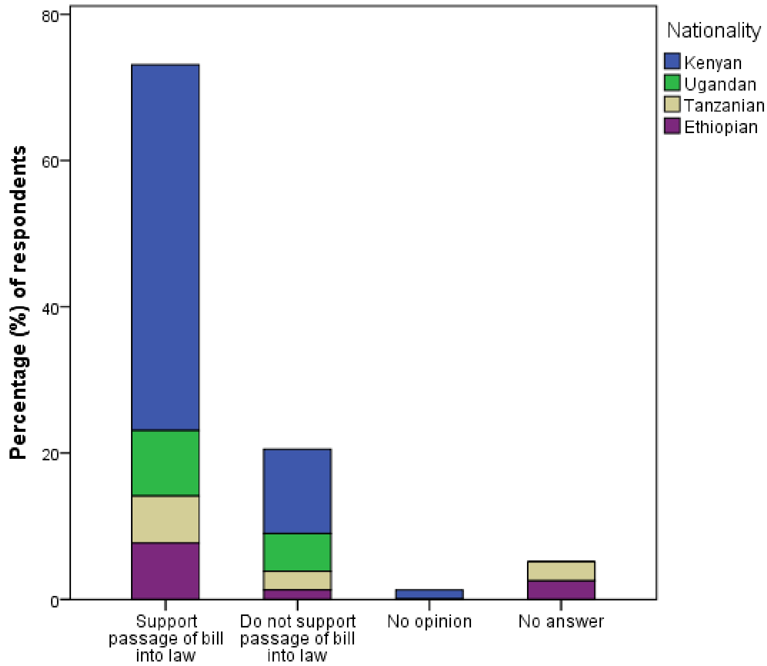


Figure 7.7. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported the passage of the Ugandan Biotechnology and Biosafety Bill into law. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the opinions expressed by stakeholders on the basis of nationality ($p>0.05$). Response rate: ~95% (74 out of 78 respondents).

However, there were significant differences in the opinions of the passage of the Biotechnology and Biosafety Bill into law on the basis of perception group and occupation (Appendices 1, Table E.4). Similarly to what has been observed previously, the majority of stakeholders from PG3 (80%) and PG4 (~89%), as well as all of the agricultural researchers and 85% of the civil servants employed in the public/private sector related to agriculture, supported the passage of the bill, while the majority of respondents from PG1 (~61%) and civil servants from NGOs (~65%) were opposed to passage of the bill (Appendices 1, Table E.1).

A few of those that were not in favour of the passage stated that the bill favours scientists and multinational corporations, while disregarding and exploiting small hold-farmers (which is in line with some of the opinions expressed during the above-mentioned UBIC debate). Others argued that the bill contains several gaps ranging from liability to risk assessment, and that increased public awareness is required before the Bill can potentially be passed. Finally, some believed that the passage of the bill would in fact restrict R&D and commercialisation of GM crops.

7.3.3. Tanzania

7.3.3.1. Development of the Tanzanian regulatory framework and policy

Tanzania has a shorter history of practical experience with agricultural biotechnology and biosafety decision-making when compared to Kenya and Uganda (Chambers, 2013). Beyond that provided by UNEP-GEF, little support was given by other biosafety services during the early stages of the development of the regulatory system, which is believed to have made room for a particularly strong influence by the CPB and the AU Model Law (Chambers, 2013).

The legal framework governing biosafety became embedded in the Environmental Management Act (EMA) in 2004 (United Republic of Tanzania, 2004a; Chambers, 2013). The EMA provided a legal and institutional mechanism for the regulation of GMOs, and requires an EIA for any project in which GMOs are to be introduced into the environment (as cited by Mwamukonda, 2015). The Act also recognised the Vice President's office, Ministry of Environment, as the National Biosafety Focal Point (NBFP), i.e. the one responsible for reviewing and approving applications related to GMOs (after being advised by the National Biosafety Committee, NBC) (Mtui, 2012; Chambers, 2013; Nyarobi & Lyimo, 2014).

The NBF was drafted in 2004 by the Vice President's Office and finalised in 2007 (United Republic of Tanzania, 2004b; Mtui, 2012; Chambers, 2013). Alongside the development of the NBF, the Tanzanian Biosafety Guidelines were issued, which applies to R&D, handling, transit, contained use, trans-boundary movement and release of GMOs and GM products (United Republic of Tanzania, 2005; Mtui, 2012). However, the biosafety regulations were not issued until 2009 (United Republic of Tanzania, 2009; Mtui, 2012; Chambers, 2013). In 2010, the National Biotechnology Policy was established to ensure that the nation had the capacity and capability to maximise the benefits of biotechnological applications, while ensuring the safety of society and the environment (United Republic of Tanzania, 2010a; Nyarobi & Lyimo, 2014).

7.3.3.2. Political will and characteristics of the regulatory framework

The National Biotechnology Policy reflects a strong political will to develop acceptance and adoption of biotechnology in various sectors. For instance, the policy's mission is to "create infrastructure for research, development and commercialization in biotechnology so as to ensure a steady flow of bio-products, bioprocesses and new biotechnologies for social and economic development of Tanzania" (United Republic of Tanzania, 2010a).

However, the main principles of the NBF and the Biosafety Regulations of 2009 are strict liability and redress and a precautionary approach (United Republic of Tanzania, 2004b; United Republic of Tanzania, 2009; Mtui, 2012). For instance, the article on liability states *"A person who imports, arranges transit, makes contained use of, releases or places on the market a GMO or product of a GMO shall be strictly liable for any harm caused by such a GMO or product of a GMO"*, while the precautionary principle shall be applied "*throughout the decision-making system of the NBF, particularly in accordance with the procedure for risk assessment, risk management and evaluation of socio-economic risks"* (United Republic of Tanzania, 2004b). Consequently, many stakeholders and developers have been apprehensive about investing and establishing projects in Tanzania (Chambers, 2013). For instance, the approval of confined field trials of GM drought-tolerant maize did not advance until recently due to the above-mentioned considerations (Chambers, 2013).

7.3.3.3. Revision of the Biosafety Regulations

In 2015, the government revised the Biosafety Regulations in order to relax the strict liability and redress (Khisa, 2015). The article on liability now adopts more of a fault-based regime, whereby researchers and research activities are exempted from the strict liability principle (Mwamukonda, 2015). The recent revision has paved way for the first confined field trial in the country, namely of maize under the WEMA project (planting started October 2016) (ISAAA, 2016a). The recent amendments is believed to have a positively impact on trade relations with neighbouring countries such as Kenya and Uganda (Chambers, 2013), and the Minister of Science and Technology, Prof. Makame Mbarawa, stated that the country will work with both private and public sector partners (James, 2015).

Findings from the Stakeholder perception survey: Opinions of the amendments made to the Tanzanian Biosafety Regulations

75.6% of stakeholder supported the amendments made to the Tanzanian Biosafety Regulations, while 15.4% did not and 2.6% did not have an opinion (6.4% did not respond) (Fig. 7.8). There were negligible significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that supported the revised regulatory framework, 41 were Kenyan (~69%), eight were Ugandan (~14%), six were Ethiopian (~10%) and four were Tanzanian (~7%) (Fig. 7.8). Of the stakeholders that did not support the amendments, five were Kenyan (~42%), four were Tanzanian (~33%), two were Ugandan (~17%) and one was Ethiopian (~85) (Fig. 7.8). Two stakeholders did not have an opinion on the matter, of which both were Kenyan (Fig. 7.8). Additionally, five participants did not reply, of which two were Ethiopian (40%), one was Kenyan (20%), one was Ugandan (20%) and one was Tanzanian (20%) (Fig. 7.8).

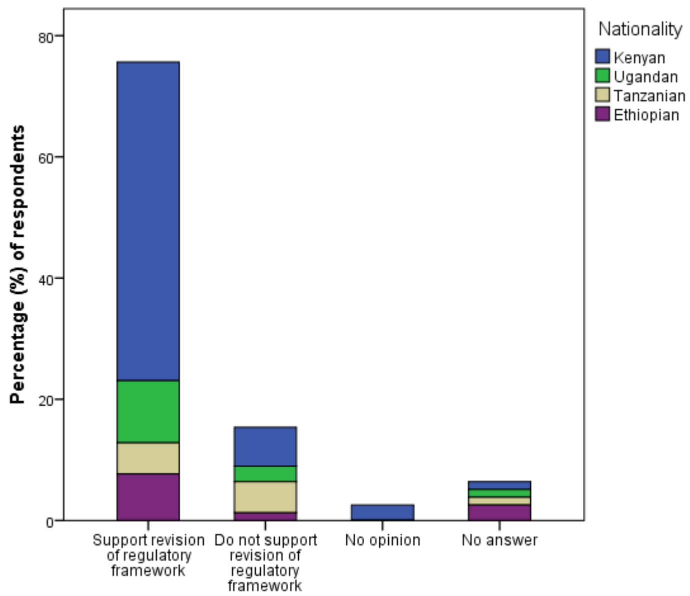


Figure 7.8. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported the revision of the Tanzanian Biosafety Regulations. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions expressed by stakeholders on the basis of nationality ($p<0.05$). Response rate: ~94% (73 out of 78 respondents).

Thus, the majority of Kenyan (~84%), Ugandan (~72%) and Ethiopian (~67%) stakeholders supported the revised regulatory framework, while Tanzanian stakeholders divided themselves equally among those in favour and those not in favour of the regulatory amendments. Additionally, as before, there were significant differences in stakeholder opinions on the basis of the respondents' perception group and occupation (Appendices 1, Table E.4). All of those that did *not* support the amendments belonged to PG1, while ~95% of both agricultural researchers and civil servants in the public/private sector related to agriculture supported the revised regulatory framework (civil servants from NGOs divided themselves relatively equally between "support" and "not in support", though a slight majority belonged to the latter) (Appendices 1, Table E.1).

Those opposed to the revised regulatory framework feared that the reduced liability would open up for rushed field trials with potentially negative impacts on the environment.

7.3.4. Ethiopia

7.3.4.1. Development and characteristics of the Ethiopian regulatory system and policy

The draft outline of the Ethiopian NBF was established in 2007 and recognised the Environmental Protection Authority (EPA) as responsible for authorisation and monitoring of GMOs (including R&D, import, export, transit, contained use and release), as well as for facilitating public awareness and participation (Government of the Federal Democratic Republic of Ethiopia, 2007). EPA led the drafting of the country's legal framework, i.e. the Biosafety Proclamation, which was passed in 2009 (Federal Democratic Republic of Ethiopia, 2009; Chambers *et al*. 2014). Hitherto, no stand-alone policy on biosafety and biotechnology exists in Ethiopia (Mtui, 2012). However, the Biosafety Framework of 2007 states that "*based on the definition given to the term 'policy' we could say there are indeed policies which address the major issues of a biosafety policy"* (Government of the Federal Democratic Republic of Ethiopia, 2007).

The Biosafety Proclamation of 2009 was based on the precautionary principle and was considered prohibitive, and a ban on both biotech R&D and planting of GM crops shortly followed (Mtui, 2012; Tefera, 2015a). Representatives from the Ethiopian government stated that GM crops would undermine farmers who already employed traditional practices of pest and weed management, and further argued that biotech crops should be developed and empirically tested by African countries to avoid external interferences (Wu & Butz, 2004; Makoni *et al*., 2006).

The NBF and Proclamation was criticised for merely focusing on the perceived environmental risks, as well as requiring a laborious socio-economic risk assessment and an advance informed agreement (AIA) to be obtained before any modified organism could enter the country (Government of the Federal Democratic Republic of Ethiopia, 2007, 2009; Abraham, 2013). The same regulatory procedures applied to any use of GMOs, whether it was meant for food and feed, contained use, confined field trials or environmental release. The AIA required the head of the competent authority to take full responsibility for all GMO-related information provided (Government of the Federal Democratic Republic of Ethiopia, 2007, 2009). Additionally, the Proclamation imposed strict requirements for labelling, insurance and monitoring of all activities associated with GMOs (Government of the Federal Democratic Republic of Ethiopia, 2007, 2009). Thus, the regulatory framework is believed to have repressed biotechnological R&D within the country and discouraged developers and foreign technology investors (Abraham, 2013).

7.3.4.2. Amendments to the Biosafety Proclamation and increased political will

However, in 2015, after years of internal governmental debate and pressure from advocates such as biotechnology researchers, the President made amendments to the Biosafety Proclamation (Federal Democratic Republic of Ethiopia, 2015; Tefera, 2015a). As a result, the AIA is only necessary in the case of environmental release, while applications for contained use are subject to a special permit (Federal Democratic Republic of Ethiopia, 2015). One of the major motivational forces behind the revision is believed to have been the potential adoption of Bt cotton as a way of meeting the growing demand of the cotton and textile sector in the country, for which field trials are currently being carried out in six agro-ecological zones (Tefera & Mohammed, 2015; Tefera & Tefera, 2015; ISAAA, 2016a).

Additionally, the government committed US$ 4.5 million towards developing a "biotechnology road map", which has led to the establishment of the Biotechnology Research Institute (ISAAA, 2016g). Recently, the Ethiopian State Minister of Environment, Forest and Climate Change, H.E. Mr Kare Chawicha, promoted to use of biotechnology as a way of facing food insecurity and economic challenges (ISAAA, 2017c).

Yet, some question whether the revised proclamation will be enough to encourage investment by foreign technology providers (Tefera, 2015a). Encouragingly, the Ethiopian government was recently commended by the US Department of Agriculture, the Bill and Melinda Gates Foundation, the Common Market for Eastern and Southern Africa (COMESA), and other international partners for their political will, and various development partners expressed their commitment to assist in capacity building (ISAAA, 2016g; Tefera, 2015a). Dr. Dawit Tesfaye Degefu predicts a bright future for biotech R&D and commercialisation in the country, but stressed the importance of taking the time to ensure that the appropriate human and technical infrastructure, regulatory capacity and sufficient public awareness is instated.

Findings from the Stakeholder perception survey: Opinions of the amendments of the Ethiopian Biosafety Proclamation

73.1% of stakeholders supported the amendments made to the Ethiopian Biosafety Proclamation, 15% did not and 7.7% did not respond (Fig. 7.9). There were weakly significant differences in the opinions of the Ethiopian government's regulatory amendments on the basis of nationality (Appendices 1, Table E.4). Of those that supported the regulatory amendments, 40 were Kenyan (~70%), eight were Ethiopian (~14%), six were Ugandan (~11%) and three were Tanzanian (~5%) (Fig. 7.9). Of those that did not support the revised regulations, seven were Kenyan (~47%), four were Tanzanian (~27%), three were Ugandan (~20%) and one was Ethiopian (~7%) (Fig. 7.9). Six respondents did not reply, of which two were Kenyan (~33%), two were Ugandan (~33%) and two were Tanzanian (~33%) (Fig. 7.9).

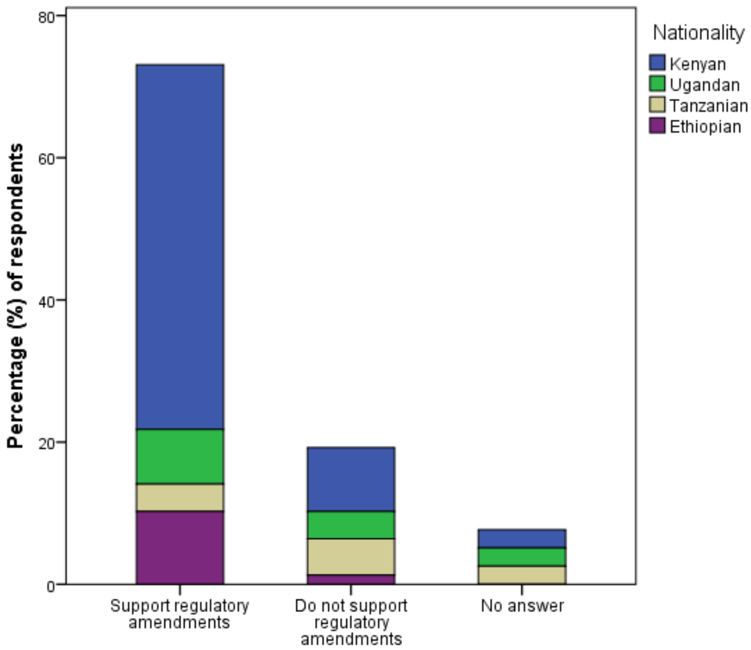


Figure 7.9. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported the amendments made to the Ethiopian Biosafety Proclamation. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions of the regulatory amendments made to the Ethiopian Biosafety Proclamation on the basis of nationality ($p<0.05$). Response rate: ~92% (72 out of 78 participants).

Thus, the majority of Ethiopian (~87%), Kenyan (~82%) and Ugandan (~55%) stakeholders supported the regulatory amendments, while a slight majority of the Tanzanian participants (~44%) did not support the revision (though it was only a matter of one respondent, thus is unlikely to have been decisive on the observed significance). Additionally, as before, there were significant differences in the opinions of the regulatory amendments on the basis of the stakeholders' perception group and occupation (Appendices 1, Table E.4), with a similar trend apparent as for opinions of other political measures described in previous sections (Appendices 1, Table E.1).

Some of those who were not in favour of the revision argued that GMOs could pose a threat to the rich agricultural biodiversity in the country.

7.3.5. Summary: Key biosafety provisions in Kenya, Uganda, Tanzania and Ethiopia

Table 7.2. Key biosafety provision of the National Biosafety Frameworks (NBFs) in Kenya, Uganda, Tanzania and Ethiopia.

Provision	Kenya	Uganda	Tanzania	Ethiopia
Lead Ministry	Science and Technology	Finance	Vice President's (VPs) Office, Ministry of Environment	The Ministry of Environment, Forest and Climate Change
Policy	National Biosafety Policy 2002	National Biotechnology Policy 2008	National Biotechnology Policy 2010	Not yet in place
Legislation	Biotechnology Act, 2009	Biotechnology and Biosafety Bill 2012	Environmental Management Act 2004	Biosafety Proclamation No 896/2015
Regulation	In place	Interim	In place	Not yet in place
Institution	National Biosafety Authority	Uganda National Council for Science and Technology - Biosafety Committee	National Biosafety Committee	Ministry of Environment, Forest and Climate Change
Precautionary principle	No	No	Yes	Yes
Mandatory labelling	Yes	Not specified; labelling policy soon to be introduced	Yes, but no specified threshold value	Yes, but no specified threshold value; will be set in the new directives
Liability and Redress	Fault-based	Fault-based	More fault-based after revision	More fault-based after revision
Socioeconomics	Yes, not specified	Yes, not specified	Yes, with details	Yes
Public awareness	Yes	Yes	Yes	Yes

Table adapted from Chambers (2013) and Kimone (2015).
Note: Certain information on the biosafety provision in Ethiopia and Tanzania was provided by, or confirmed through personal correspondence with, stakeholders that participated in the social science study, who are to be maintained anonymous due to privacy reasons.

7.4. Regional harmonisation of biosafety and biotechnology laws, regulations and policies

Regional harmonisation of biosafety and biotechnology laws and regulations have many proposed benefits – laws and policies developed collaboratively can allow for greater regulatory efficiency and a simplified approval process, sharing of best practice and expertise, and facilitate capacity building and pooling of scientific, technical and regulatory resources (Anderson & Jackson, 2005; Paarlberg *et al*., 2006; Gruère & Sengupta, 2009). Harmonisation can be particularly beneficial for countries that are too poor to support the appropriate infrastructure for agricultural R&D and regulatory requirements. Additionally, harmonisation efforts can work to mitigate negative trade effects caused by movement of GM products across border, and can further help support greater trade, commerce and economies of scale, as well as promote the East Africa region as a bigger and more lucrative market for investors (Chambers, 2013; Chambers *et al*., 2014). However, harmonisation is both a technical and political process, and uniting economic and social interests, as well as different standpoints and approaches to biosafety, might prove challenging (Chambers, 2013). Indeed, public and governmental attitudes and national biosafety regimes can be poorly aligned amongst neighbouring countries (though recent progress in most of the study countries indicate a move towards commercialisation), and many countries exhibit internal conflicts on the topic (as seen in the case of e.g. Kenya). Furthermore, as one of the surveyed stakeholders expressed, harmonisation could compromise a country's autonomy and independent decision-making concerning GMOs, Dr. Degefu was also opposed to regional harmonisation due the above-mentioned reasons and referred to recent challenges faced by the EU, including the UK's decision to leave the union (i.e. "Brexit").

Current harmonisation efforts

Efforts to regionalise and harmonise biosafety regulations have been carried out through initiatives such as the East African Legislative Assembly (EALA) of the East African Community (EAC) and the Regional Approach to Biotechnology and Biosafety Policy in Eastern & Southern Africa (RABESA) project established by COMESA (Chambers, 2013; ISAAA, 2014). Kenya, Uganda and Tanzania are all part of the EAC, while Kenya, Uganda and Ethiopia are members of COMESA (Tanzania withdrew in 2000; BBC, 2000) (ISAAA, 2014).

COMESA has been the most successful in turning its efforts into reality (Chambers *et al*., 2014); the Regional Biotechnology and Biosafety Policy Implementation Plan (COMBIP) was established in 2015 with the aim of turning the COMESA Policy on Biotechnology and Biosafety into a region-wide program (Chambers *et al*., 2014; ISAAA, 2015f). Its mission is to promote the adoption of biotech crops, as well as support trade of GM technology, thus turning Member States into active participants in the global biotechnology enterprise (ISAAA, 2015f).

Additionally, the Association of National Biosafety Agencies in Africa (ANBAA) was established in 2015 under the auspices of ABNE and NBA in Kenya, and consists of regulatory agencies from 19 African countries, including Kenya and Uganda. The aim of ANBAA is to, amongst others, harmonise biosafety systems across the continent, facilitate free sharing of information and expertise on GMOs, and to strengthen the voice of Africa internationally on issues related to biosafety (National Biosafety Authority, s.a.; ABNE, 2016; ISAAA, 2016a).

However, harmonisation efforts do not necessarily work in favour of the widespread adoption of GM crops. For instance, the EALA initiative may have the unexpected outcome of giving rise to new debates concerning biotech crops which could create lee-way for anti-GMO lobbying in countries such as Kenya and Uganda (which could influence decision-making concerning e.g. the ban on GM imports and the passage of the Ugandan Biotechnology and Biosafety Bill into law, respectively) (Chambers, 2013). Additionally, some harmonisation initiatives emphasise on the need for a more precautionary approach to biosafety, including the Southern Africa Committee on Biotechnology and Biosafety (SACBB) established by the Southern Africa Development Community (SADC), where Tanzania is a member (Chambers, 2013). However, SADC have yet to reach much consensus on the matter of transgenic crops (Chambers, 2013).

Findings from the Stakeholder perception survey: Opinions of harmonisation of biosafety and biotechnology laws and regulations in East Africa

70.5% of stakeholders “strongly agreed” that East African countries should strive for regional harmonisation of biosafety and biotechnology policies, while 14.1% “agreed”, 3.8% “somewhat agreed” and 10.3% “strongly disagreed” (1.3% did not have an opinion; not shown in Fig. 7.10) (Fig. 7.10). There were significant differences in the opinions of regional harmonisation on the basis of nationality (Appendices 1, Table E.4). Of the stakeholders that “strongly agreed”, 38 were Kenyan (~69%), 10 were Ugandan (~18%), six were Ethiopian (~11%) and one was Tanzanian (~2%) (Fig. 7.10). Of those that “agreed”, eight were Kenyan (~73%), two were Tanzanian (~18%) and one was Ethiopian (~9%) (Fig. 7.10). Of the stakeholders that “somewhat agreed”, two were Tanzanian (~67%) and one was Ethiopian (~33%) (Fig. 7.10). Finally, of those that “strongly disagreed”, four were Tanzanian (50%), two were Kenyan (25%), one was Ugandan (12.5%) and one was Ethiopian (12.5%) (Fig. 7.10). One stakeholder (Kenyan) did not have an opinion (not shown in Fig. 7.10).

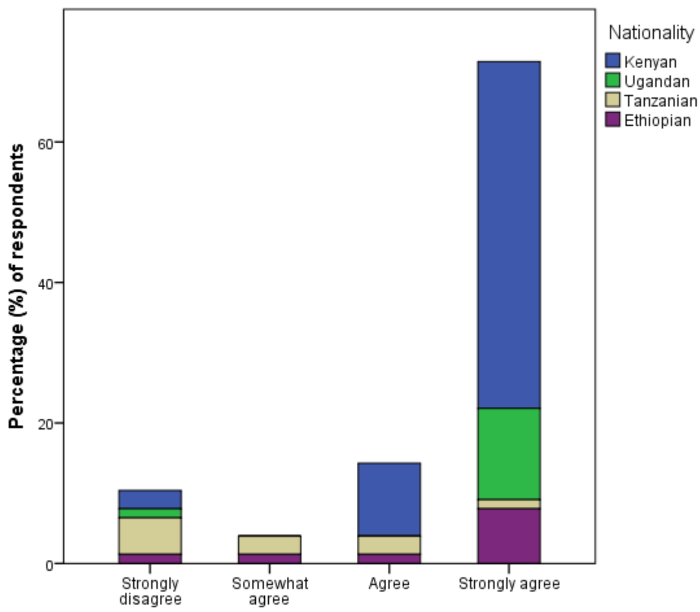


Figure 7.10. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that agreed that East African countries should strive for regional harmonisation of biosafety laws, regulations and policies. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions of regional harmonisation of biosafety laws, regulations and policies on the basis of nationality ($p<0.01$). Response rate: 100% (78 out of 78 participants).

Thus, the majority of Ugandan (~91%), Kenyan (~78%) and Ethiopian (~67%) stakeholders "strongly agreed", while only a single Tanzanian stakeholder was found to"strongly agreed" (~11%) and the majority (~44%) "strongly disagreed". Additionally, there were significant differences in the opinions of regional harmonisation on the basis of perception group and occupation (Appendices 1, Table E.4). All of those that "strongly disagreed" belonged to PG1, though just as many stakeholders from this perception group were found to "strongly agree" that the East African countries should strive for harmonisation (Appendices 1, Table E.1). ~88% of respondents from PG4 "strongly agreed", thus making up the majority of this response category (Appendices 1, Table E.1). In terms of occupation, 75% of civil servants in the public/private sector related to agriculture, 80 % of extension workers and ~81% of agricultural researchers were found to "strongly agree". Though civil servants employed in NGOs constituted 75% of the response category "strongly disagree", the majority (~59%) of respondents from this occupational group was in fact in strong support of harmonisation efforts (Appendices 1, Table E.1).

Of those that agreed that East African countries should strive for harmonisation, the majority found it "very likely" that the proposed benefits would be realised through such efforts, including "greater regulatory efficiency and simplified approval processes", "facilitation of capacity building and sharing of experiences", "transfer of technologies and policies", "ease of trade and enhanced commerce" and "mitigation of negative trade effects" (Table 7.3).

Table 7.3. Likelihood of proposed benefits realised through harmonisation of biosafety & biotechnology laws and regulations, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1] ; in % and [number] of respondents.

	Not likely	Somewhat likely	Likely	Very likely	Do not know
Greater regulatory efficiency and simplified approval processes	2.8 [2]	2.8 [2]	15.3 [11]	76.4 [55]	2.8 [2]
Facilitate capacity building and sharing of experiences	1.4 [1]	2.9 [2]	25.7 [18]	68.6 [48]	1.4 [1]
Transfer of technologies and policies	2.8 [2]	7.0 [5]	25.4 [18]	62.0 [44]	2.8 [2]
Ease of trade and enhanced commerce	1.4 [1]	2.9 [2]	26.1 [18]	68.1 [47]	1.4 [1]
Mitigate negative trade effects	5.6 [4]	8.5 [6]	29.6 [21]	55.0 [39]	1.4 [1]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
Note: The expected number of respondents was 69 (i.e. based on the number of stakeholders that had responded "somewhat agree", "agree" or "strongly agree" to the question of whether East African countries should strive for a regional harmonisation of biosafety regulations and policies), while the observed number was between 70 and 72 in some cases (the total number of participants was 78).

7.5. Concluding remarks

The lack of facilitating, efficient and technically competent regulatory systems is considered a constraint on the adoption of biotech crops in many East African countries (Ezezika, 2012; Chambers, 2013). Kenya and Uganda boast relatively long histories of practical experience using agricultural biotechnology, and capacity building initiatives such as UNEP-GEF and PBS made their mark early on during the development of the regulatory systems. As a result, Kenya and Uganda developed regulations and policies that assumed more of a science, fault and result/product-based approach. Contrastingly, the establishment of the Tanzanian and Ethiopian biosafety frameworks were strongly guided by the CPB, the precautionary principle and the AU Model Law which, initially, led to more risk-oriented and process-based regulations with strict provisions related to liability, redress and socio-economic considerations (for more information on the latter, see Chapter 23).

However, the approach assumed by Kenya and Uganda does not guarantee successful adoption of GM crops, and there is often some discrepancy between what is expressed in the national biotechnology policies and the biosafety laws and regulations. The former generally contain statements that recognise the potential that the technology hold, while the latter can exhibit restrictive and stringent provisions that conflict with what is stated in the policies. The Kenyan ban on GM imports is a prominent example, though all study countries demonstrate examples of such inconsistencies. Additionally, regulatory decision-making is influenced by a variety of dynamics – including culture, ethics, socio-economics and the political climate – which complicates matters further and may result in weak, inefficient and contradictory attitudes of regulatory bodies.

Still, discrepancies and sluggish progress is perhaps to be expected in countries where regulatory decision-making on biosafety and biotechnology is still evolving, particularly so when there is limited capacity and practical experience with the technology. Furthermore, the fact that the first environmental release of GM crops has been approved in Kenya, and regulatory amendments have recently been made by the Ethiopian and Tanzanian governments, indicate a move towards commercialisation. In the case of Uganda, only time will tell if there is adequate political will to pass the Biotechnology and Biosafety Bill into law. However, Uganda is a prime example of how established regulations are not always a prerequisite for R&D, perhaps not even for commercialisation (indeed, laws may even become restrictive on R&D and the uptake of technology). In fact, the first Bt variety and GM soybean grown in India and Brazil, respectively, came from illegal seeds obtained across the borders (da Silveira & Borges, 2005). Thus, Dr. Oduor predicts that if East African farmers saw first-hand the advantages that GM crops may offer, they may acquire such seeds from their GM crop-adopting neighbours (e.g. Sudan); “Farmers would have no misgivings about growing and eating GM crop products regardless of whether or not a biosafety law was in place”, said Dr. Oduor.

Chapter 8. The International GMO Debate

8.1. Europe's relationship to agricultural biotechnology and the EU regulatory system

Consumer perceptions. For many Europeans, their first encounter with GM foods was being told that they were already consuming it; they were told that Monsanto was comingling GM and non-GM products, thus making it more or less impossible to supply GMO-free soya, which was deemed a deliberate strategy to enforce widespread acceptance of biotech crops (McHughen, 2000). Furthermore, Monsanto was found guilty of false advertising by the Advertising Standards Authority (ASA), including incorrectly stating that transgenic potatoes had been approved by regulatory agencies in 20 countries (Gregoriadis, 1999). Additionally, an advert featuring a biotech tomato with the statement "The farmer can spray substantially less insecticide on his field" was found to be misleading because the effects had not yet been fully documented. Consequently, biotech crops started to gain considerable controversy among some European consumers, food retailers and regulators, and a moratorium on the further approval and commercialisation of biotech crops was established by the EU in 1998 (Financial Times, 2006; Gruère & Sengupta, 2009). Though the moratorium was lifted in 2004, a certain level of scepticism appears to have remained in several European countries (Gaskell *et al*., 2010; European Commission, 2010)

Regulatory approach to biosafety and biotechnology. The EU has established a separate, elaborate, stringent and precautionary regulatory program for GMOs and products thereof (Paarlberg, 2001). The European Commission (EC) has only approved a single GM crop for commercialisation, namely Bt maize (MON810), which is grown in Spain, Portugal, the Czech Republic and Slovakia (Romania discontinued planting in 2016) (ISAAA, 2016a). The cautious approach of many Member States became evident when the National "opt-out" Law was proposed by the EC (Laaninen, 2015). The law allows Member States to opt-out on the cultivation of authorised GMOs on their territory based on proposed health and environmental risks (James, 2015). Within the deadline of the application, 19 out of 28 countries intended to opt-out (Savage, 2015).

Labelling and traceability. A country or company is only allowed to export food products to the EU if the product is listed as compliant with the food and safety rules (European Commission, 2004). There is a threshold value of 0.9% for transgenic events approved for food and feed, and subsequent labelling requirements apply (European Union, 2003). There is a 0.1% threshold in cases were the event has been approved in other jurisdictions and has previously been submitted for approval to the EU, while a zero tolerance policy exists for unapproved GMOs (as cited by James, 2015).

Criticism of the EU regulatory system. The EU legislation has been criticised on several point, including (i) being out of proportion compared to other science-based activities; (ii) assuming that biotech crops are inherently more risky than conventional crops (despite the fact that the Research Directorate of the EU reported that three decades of research had shown that "biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies"; European Union, 2010); (iii) not balancing the risks against the potential benefits to the producer, consumer and the environment; and (iv) creating obstacles for the development of sustainable agriculture (Euractiv, 2010; Fagerström *et al*., 2012). In fact, in 2003, the US, Canada and Argentina filed a complaint with the Dispute Settlement Body (DSB) of the WTO against the EU, arguing that their regulatory system was non-scientifically justifiable and excluded foreign GM products on unfair premises (ICTSD, 2003).

Concluding remarks. However, the impression that Europeans are completely against GM products or that the EU remain largely GM free is a fallacy (Komen & Wafula, 2014). At least 86 GM products have been approved, including transgenic soybeans, cotton, maize, oilseed rape and sugar beet (Komen & Wafula, 2014; Aldemita *et al.,* 2015). Furthermore, the EU imports substantial amounts of GM food and feed to meet the growing demands of the poultry and livestock sectors – more precisely ~40 million tons each year, of which 35 million constitute soymeal and soy grains that mainly derive from countries in Northern and Latin America (James, 2015). Consequently, approximately 80% of the imported soybean meal originates from transgenic soybeans (Komen & Wafula, 2014).

8.2. The US's relationship to agricultural biotechnology and the US regulatory system

The US makes no significant distinction between GM food crops and their conventional counterparts during safety assessment, and it is the end characteristics of the final product that is evaluated during risk assessment as opposed to the underlying technical process (National Research Council, 1989; Paarlberg, 2001). Consequently, a transgenic product may be released onto market if it has successfully passed tests of allerginicity, digestivity, toxicity, etc. (Adenle *et al*., 2011).

The less risk-averse approach of the US has been explained by several factors, including (i) a decline of political saliency of consumers and environmental policies; (ii) decreased influence by civic interests and NGOs (Ansell *et al*., 2006; Doh & Guay, 2006); (iii) the presence of a well-established set of national regulatory bodies (as opposed to the EU, which attempts to establish a regulatory structure capable of ensuring safety of food produced in all Members States, whereby each country has its own regulatory institution); (iv) a higher degree of public acceptance (Enriquez & Goldberg, 2000; Lynch & Vogel, 2001); and (v) due to cultural differences (Montpetit & Rouillard, 2008).

Up until recently, no mandatory labelling of GM foods or products existed in the US (Meijer & Stewart, 2004). However, in 2016, former President Barack Obama signed the GMO Labelling Bill into law, which requires labelling of GM ingredients (Dinan, 2016). If and how this will impact on the US and the global agri-biotech industry remains to be seen.

8.3. The GMO "tug-of-war"

Many paint the picture of the GMO debate as a "cold war" between the anti-GMO+ advocates (including the EU, Japan, Switzerland and South Korea) and the GMO optimists (including the US, Brazil, Canada and South Africa) (Meijer & Stewart, 2004). Furthermore, international civil society organisations and anti-GMO NGOs on one hand (see Chapter 9), and the biotechnology industry and pro-NGOs on the other, further exacerbate this polarised "tug-of-war".

The dispute between the pro and anti-GMO advocates is believed to create obstacles for the adoption of new technology in Africa, both directly and indirectly (James, 2015). For many developing countries, the safest approach has been to avoid taking resolute decisions on the matter of GMOs, which might help explain the slow approval process of biosafety laws or delays in lifting of bans on GMO imports (Meijer & Stewart, 2004; Makinde *et al*., 2009). However, as many African countries exhibit close cultural ties and trade relationships with Europe stemming from the colonial time, they are considered more likely to amend to the attitudes and practices of the European system (Paarlberg, 2010b). For instance, the author of "Twelve Reason for Africa to Reject GM crops" (see Chapter 9 for more information) said: "Europe has more knowledge, education. So why are they refusing [GM foods]? That is the question everyone is asking" (Hand, 2006).

Furthermore, European-based lobbying has seen to directly discourage the use of biotech crops in Africa. For instance, in response to the G7's New Alliance for Food Security and Nutrition – a programme that aims to develop PPPs for increased agricultural production in Africa mainly through encouraging private investment – the EU Parliament endorsed a report which urged all G7 members not to support transgenic crop research and cultivation in Africa (Global Justice Now, 2016; Ngotho, 2016b).

The Kenyan Member of Parliament (MP) John Serut criticised the report, saying: "[…] it looks like it is intended to make Africa remain in subsistence farming" (Ngotho, 2016b), while the Director of ISAAA *Afri*Center, Dr. Karembu, argued that the report was not in line with Article 16 and 19 of the CBD, which states that signatory parties must engage in biotechnology transfer (Karembu, 2016). The report also provoked strong emotions in Dr. Oduor: "This is the worst possible statement that could come from the EU. It is hypocritical to expect Africa not to touch GM foods, while they themselves [the EU] import substantial amounts to feed their animals, which they themselves feed on. It is time for Africa to ignore the EU and tell them to mind their own business; their relationship to food is completely different – they have abundances of it, high production, different culinary habits and preferences, and are not exposed to the same environmental constraints".

The use of development assistance, trade and aid to promote opposing viewpoints in the GMO debate. Both Europe and the US have been criticised for using development assistance, trade and aid to promote their opinions in the GMO debate (Meijer & Stewart, 2004; GRAIN, 2005). For instance, it is a sobering thought that several PPPs have been or are being funded by USAID (e.g. virus-resistant sweet potatoes, BXW-resistant bananas, WEMA and NEWEST Rice) and in some cases UKAID (e.g. NEWEST Rice). Additionally, food aid delivered by USAID has often been in the form of GM food and/or products, which has provoked huge debates in some African countries; back in 2002, at the brink of the worst food crisis that the Southern part of Africa had experienced in ten years, Zambia refused to accept transgenic maize offered by USAID (Paarlberg, 2014). Countries such as Zimbabwe, Tanzania, Mozambique and Malawi accepted the food aid, but requested it to be milled before entry into the country (Komen & Wafula, 2013; Chambers *et al*., 2014). Though the Zambian government stated that the refusal was due to concerns regarding safety and inadequate scientific information, others speculate that the decision was based on fear of losing market access to Europe and due to political economy (further elaborated on in Chapter 19), as well as being influenced by NGO lobbying (Chapter 9) (Cooke & Downie, 2010; Paarlberg, 2014).

Capacity building programs initiated by the EU are often aimed at helping exporting countries in complying with requirements of labelling and traceability, and/or developing regulatory systems that align with the precautionary principle (Meijer & Stewart, 2004). The US on the other hand, aims to promote R&D by establishing infrastructure and supporting training and technological development (e.g. the Agricultural Biotechnology Support Project II initiated by USAID) (Meijer & Stewart, 2004). The two differing approaches have been seen to directly conflict with each other; for instance, a Germany-led project collaboration with the AU, which aimed to develop biosafety and regulatory capacity building in Eastern and Western Africa in accordance with the AU Model Law, conflicted with a similar US-funded biosafety plan led by members of the CGIAR which was more in line with the attitudes of GMO proponents (Masood, 2003). Consequently, international development assistance activities have often failed to provide a balanced approach to capacity building for R&D and regulatory decision-making (Meijer & Stewart, 2004).

The GMO conflict and legal uncertainties. The GMO conflict has also created obstacles for the WTO, the Codex Alimentarius and CBP in establishing clear regulatory rules for trade of GMOs (Meijer & Stewart, 2004). In some respects, this could be beneficial for developing countries as it allows more time to "play around" with different policies for development and regulation of biotech crops, as well as learn from other countries' experiences, before settling on a well-founded and informed decision on the use of biotech crops (Meijer & Stewart, 2004). However, without clear guidelines on trade regulations, developing countries could become more vulnerable to pressure and claims from GMO pessimists and optimists alike, in terms of what international laws requires and/or allows them to do (Meijer & Stewart, 2004). Additionally, lack of clear regulatory guidelines makes it difficult to foresee future trends and export markets for biotech products, which may leave many countries in a "state of paralysis" (Meijer & Stewart, 2004).

8.4. China and other emerging economies: New key players in the international GMO debate?

8.4.1. China

China has indicated intensions of becoming a major investor and developer of biotech crops. For instance, the country has increased the scale and type of varieties of transgenic plants (Deutsche Welle, 2016). Additionally, the state-owned ChemChina recently announced its take-over of Swiss-owned, multinational agribusiness Syngenta (see Chapter 13), which after several months of delays due to hold-backs from European officials was approved in April 2017 (Bray, 2016; Wu, 2016; Fioretti & Franklin, 2017; White, 2017).

Furthermore, during the last two decades, China has shown increased interest in African resources, as well as providing more aid, cancelling debts and investing in infrastructure (including roads, schools, hospitals, and the agricultural sector) (Rubinstein, 2009). For instance, China has pledged to spend US$800 million to improve the agricultural infrastructure in Mozambique, and a substantial number of Chinese agricultural experts currently help maintain agricultural research stations and investment projects across southern and eastern Africa (Rubinstein, 2009). Some say that "in return", Africa now supplies more than a third of China's oil (Rubinstein, 2009).

Chinese interests and investments in African countries have also gone towards agricultural biotechnology and related capacity building efforts (Meijer & Stewart, 2004). For instance, in 2009, the Chinese Academy of Agriculture (CCA) established the Green Super Rice for the Resource Poor of Asia and Africa, with the aim of delivering high-yielding rice varieties with resistance to abiotic stressors to seven African countries (AATF, 2009). According to the CCA, the project is estimated to increase production of rice by 20%, thus contributing to feeding 20 million poor farmers. In Ethiopia, the Ethiopia-China Agricultural Technology Demonstration Center was established in 2011 (AATF, 2010; Government of the Federal Democratic Republic of Ethiopia, s.a.). Similarly, a contract to build a demonstration centre for rice research in Tanzania was signed in 2006, with the aim of using Chinese technologies to improve the yield of the New Rice for Africa-project (NERICA) (however, the project has suffered from considerable delays) (WARDA, 2008; AATF, 2010).

Some critics argue that Chinese interests in Africa comes purely from a place of self-interest, with the goal of acquiring cheap and underutilise land, cultivate food using Chinese labour and technology, and to ship the food back to China for local consumption (Rubinstein, 2009). The Chinese have dismissed such statements, arguing that it would be unrealistic and economically impracticable due to "poor infrastructure, high shipping costs, and unstable governments [in Africa]" (Rubinstein, 2009). Encouragingly, rather than simply securing land leases and investing heavily in land rights, the Chinese appear to focus on cooperatives and infrastructure, which might suggest a more supportive approach (Rubinstein, 2009). Thus, though it may be naive to assume that China will not take some advantage of African food resources, Chinese investment could hold potential benefits for the further development of the agricultural sector in East Africa by improving infrastructure, education and access to available technologies and investment capital.

Still, some questions remain: What impact will will China have on future regulatory decision-making and attitudes towards biotech crops in East Africa? Will the Chinese promote a more facilitating and liberal attitude and actually deliver pro-poor products to market where other international players have failed? Could China – which faces the daunting challenges of feeding its 1.37 billion people with little arable land (World Bank (s.a.-a) – represent a new market for African countries to tap into? Or will Africa – yet again – find herself exploited and "neo-colonised" by someone "bigger and stronger"?

8.4.2. Other emerging economies and south-south cooperation

As emerging economies such as Brazil, Argentina, India and Indonesia have started to develop GM plant varieties and increased land areas devoted to commercialised events (ISAAA, 2016a) – some of which are of particular interest to East Africa, including rice, beans, sugarcane and bananas – African countries could become inspired to follow pursuit. Furthermore, countries such as Brazil have started to invest in joint agriculture R&D partnerships and donor relationships in Africa during recent years. For instance, the two-year long ISAAA-Brazilian Agricultural Research Corporation (EMBRAPA)-Science Foundation for Livelihoods and Development (SCIFODE) Partnership Project aimed to link Brazilian, African and Latin American and Caribbean (LAC) expertise and institutions (ISAAA, 2015g). The project involved seeing-is-believing tours to Brazil, Kenya and Uganda, as well as discussions on the barriers associated with access, adoption and acceptance of GM crops. As the project came to an end in 2015, new partnerships had been formed, including a Material Transfer Agreement (MTA) to deploy biotech soybean in Uganda (ISAAA, 2015g).

Could emerging economies and development of south-south cooperation represent a new market for East African countries, or potentially represent the nucleus of a new bloc of developing countries with an interest in agricultural development and biotechnology, with enough "weight" to create a shift in the power dynamic of the international GMO debate?

Though the term "south-south" has become somewhat trendy over the years, Dr. Oduor argues that it might be time to move away from concepts such of North-North, North-South and South-South, and instead start recognising the uniqueness, strengths and concerns of each specific nation, and how such considerations can be employed in a way in which all cooperating parties can gain from it. Indeed, it is important to recognise that, though sharing some commonalities, developing countries may exhibit diverse economic and research interests (e.g. in terms of crop varieties and transgene traits of interest), may have conflicting regulatory approaches to biosafety and biotechnology, as well as different socio-economic, socio-political, cultural and environmental conditions and constraints.

8.5. Findings from the Stakeholder perception survey

78.2% of stakeholders considered a “non-polarised debate among pro and anti-GM advocates” as an “important” or “very important” measure to allow for the successful widespread adoption of GM crops (Chapter 24, Table 24.18). Additionally, “less interference from the international community” was perceived as an “important” or “very important” measure by 71.8% of participants (Chapter 24, Table 24.18). Contrary, “increased interference from the international community” was considered the least important measure, though 50% of stakeholders still found it “important” or “very important” (Chapter 24, Table 24.18).

Furthermore, 66.7% of stakeholders believed it was “appropriate for the international community to promote the use of GM crops as a solution for the poverty problem in Africa”, while 32.1% found it “inappropriate” (1.3 % did not respond; not shown in Fig. 8.1) (Fig. 8.1). There were no significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that found it “appropriate”, 34 were Kenyan (~65%), seven were Ethiopian (~13%), six were Ugandan (~12%) and five were Tanzanian (~10%) (Fig. 8.1). Of the stakeholders that found it “inappropriate”, 15 were Kenyan (60%), five were Ugandan (20%), three were Tanzanian (12%) and two were Ethiopian (8%) (Fig. 8.1). One respondent (Tanzanian) did not reply (not shown in Fig. 8.1).

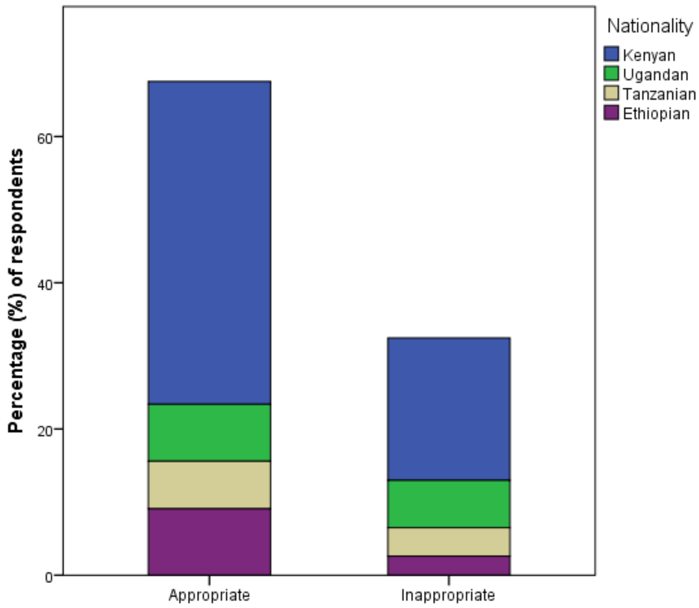


Figure 8.1. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that thought it was appropriate for the international community to promote the use of genetically modified (GM) crops as a solution for the poverty problem in Africa. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were no significant differences in the opinions expressed by stakeholders on the basis of nationality ($p>0.05$). Response rate: ~99% (77 out of 78 participants).

However, there were significant differences in the opinions of whether or not it was appropriate for the international community to promote the use of GM crops on the basis of the participants' perception group (PG) and occupation (Appendices 1, Table E.4). 65% and ~89% of respondents from PG3 and PG4 found it "appropriate", respectively, while ~72% of respondents from PG1 found it "inappropriate" (Appendices 1, Fig. E.5.4a). Furthermore, ~91% of extension workers, ~76% of agricultural researchers and 70% of civil servants employed in the public/private sector related to agriculture found it "appropriate", while ~65% of the representatives from NGOs found it "inappropriate" (Appendices 1, Fig. E.5.4b).

Considering what has been discussed in previous sections – whereby interference by the international community has at times worked to negatively impact the uptake of new technology – it may appear contradictory that a relatively high number of stakeholders supported increased interference and the promotion of biotech crops in Africa by the international community. Still, this is likely a testament of the importance that international support may have, and stakeholders further identified "assisting in public biotechnology research programs", "awareness campaigns", "initiating public-private partnerships (PPPs) with multinational biotech companies for technology-sharing" and "aiding in developing laws, regulations and policies concerning biosafety and biotechnology" as important contributions by the international community (Table 8.1).

Table 8.1. Level of agreement for various ways of support by the international community for advancing the agricultural biotechnology sector in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopia stakeholders[1]; in % and [number] of total respondents [78].

	Agree	Disagree	No answer
Assist in developing the country's public biotechnology research program	96.2 [75]	1.3 [1]	2.6 [2]
Awareness campaigns	87.2 [68]	10.3 [8]	2.6 [2]
Initiate public-private partnerships (PPPs) with multinational biotech companies for technology-sharing	84.6 [66]	11.5 [9]	3.8 [3]
Aid in developing laws, legislations and policies	82.1 [64]	14.1 [11]	3.8 [3]

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

8.8. Concluding remarks

The international community appears to have undermined the African countries' own independent judgment on biotech crops and failed to recognise that the African governments should be the primary decision-makers on GMO policies in their countries. Furthermore, the international GMO debate has resulted in fragmented international development assistance, lack of clear guidelines and legal uncertainty. As a consequence, many African countries have become passive bystanders in the international debate, whereby many have adopted a "wait-and-see" approach, perhaps due to political economy, fear of upsetting relationships with the EU, and potential loss of trade and market opportunities.

It is unlikely that the main participants of the "GMO Cold War", including the US and the EU, will stand down anytime soon in order to create a neutral space in which the East African countries can make their own independent decisions. Indeed, a variety of factors – political, economic, legal, historical and cultural – is likely to have undermined the potential for cooperation and a mutually beneficial outcome for EU and the US (Pollack & Shaffer, 2009). In this respect, it is important that the international community aim for at least a partial truce, and focus efforts on improving the scientific, infrastructural, technical and managemental capacity of the recipient country; and do so in a clear and consistent way. For instance, Meijer & Stewart (2004) suggests that one international organisation, such as the FAO, takes a coordinating leadership role in integrating international assistance initiatives.

Chapter 9. The Influence of Non-Governmental Organisations on GMO Decision-Making in East Africa

9.1. Non-governmental organisations (NGOs) and their general stance on genetically modified organisms (GMOs)

A non-governmental organisation (NGO) is defined as a private, not-for-profit organisation which pursues a specific public aim by trying to influence political outcomes through lobbying, advocacy and various ways of pressure (Arts & Mack, 2006). NGOs may promote themselves as advocates of social justice, of the rural poor, of the environment, of alternative farming, as opponents of multinational-led globalisation, or driven by religious motivational forces (Paarlberg, 2014).

A number of NGOs – most of which are European-based, though several exist in e.g. the US and Canada (e.g. Center for Food Safety) – display cautious or even hostile attitudes towards GM crops (Paarlberg, 2014). The major concerns expressed by such anti-GMO groups relate to (i) Farmers' Rights; (ii) concentration of power in the agricultural food chain by corporate multinationals; (iii) loss of traditional crops and biodiversity, and (iv) various concerns related to trade, environment and health (Ezezika *et al*., 2012; Kameri-Mbote, 2012). Consequently, anti-GMO groups have attempted, sometimes successfully, to influence negotiations and decision-making concerning biosafety and biotechnology (Arts & Mack, 2006; Paarlberg, 2014). As a result, NGO lobbying has been recognised as a major obstacle to the acceptance of biotechnology, also in developing countries (Nuffield Council on Bioethics, 2004; Ezezika *et al*., 2012).

The success of NGO campaigns can partly be accredited to the amount of trust that society seems to bestow on such organisations, which might reflect the fact that NGOs do not, strictly speaking, seek profit as opposed to corporations and governments (Edelman, 2012; Paarlberg, 2014).

9.2. The impact of non-governmental organisational lobbying in Africa

Many African delegates first got introduced to anti-GMO NGOs during the CBP negotiations, whereby groups such as Greenpeace, Friends of the Earth, and Third World Network promoted the potential risks associated with transboundary movement of GMOs and GM products to biological diversity, traditional agriculture and indigenous people (Arts & Mack, 2006; Paarlberg, 2014). Since then, anti-GMO forces have left a significant mark on the continent, and have amongst others played a part in the rejection of GM food aid. For instance, during the 2002 drought in Southern Africa, NGOs portrayed the reluctance of the Americans to label GM food aid as a way of dumping their surplus of unhealthy commodities onto the poor. USAID argued that the shipments had already been approved in the US, thus no further labelling was required (Paarlberg, 2014). Also the Angolan decision to reject un-milled GM maize in 2004 was likely influenced by Friends of the Earth's regional campaign to "challenge the myth of GM crops as a solution to hunger and poverty" (Friends of the Earth, 2007; Paarlberg, 2014).

Additionally, when the World Summit on Sustainable Development was held near Johannesburg in 2002, the association Participatory Ecological Land Use Management (PELUM) (i.e. a network of NGOs and civil society organisation) organised a four-day "pilgrimage" whereby 120 farmers announced their opposition to GMOs (Paarlberg, 2014). The campaign was funded by several NGOs situated in Europe, including Hivos (Humanist Institute for Cooperation) (the Netherlands), GOS-Belgium, MISEREOR (Germany), and Find Your Feet (UK) (Paarlberg, 2014).

9.3. Non-governmental organisations (NGOs) and their activities in East Africa

Several of the surveyed farmer groups, most of which were Kenyan, told of NGO campaigns which advocated the potential health hazards associated with the consumption of GM products. Indeed, international, regional and local NGOs are active in all study countries investigated, but to a variable degree. Of the international key players are ActionAid (active in all countries; ActionAid, s.a.), Friends of the Earth (most prominent in Uganda and Tanzania; Friends of the Earth International, s.a.), Oxfam and Greenpeace (particularly active in Kenya; Kameri-Mbote, 2012), and Sasakawa Africa Association (carries out activities in Ethiopia and Uganda; Sasakawa Africa Association, s.a.). Both ActionAid and Oxfam have previously argued that biotech crops will not benefit smallholder farmers and fear the impact that IPRs may have on traditional seed saving and Farmers' Rights (further discussed in Chapter 13) (Kameri-Mbote, 2012). Additionally, ActionAid-Uganda has carried out a campaign which linked GM foods to health issues such as cancer and infertility, though the organisation later apologised and acknowledged that the campaign was misguided and inappropriate (ActionAid, 2015; Karembu, 2017). Still, ActionAid is believed to have been an influential force in delaying the passage of the Ugandan Biotechnology and Biosafety Bill into law (Atkinson *et al*., 2015).

PELUM-Kenya has been of the general view that governments should tighten the regulations governing GMOs (PELUM, s.a.; Kameri-Mbote, 2012). In Kenya, PELUM together with ActionAid initiated a media campaign against the draft National Biosafety Bill (before it was enacted in 2009) (PELUM, 2004; Paarlberg, 2014). In association with this campaign, PELUM also produced an article titled "Twelve Reason for Africa to Reject GM crops", which stated that "Africa is in danger of becoming the dumping ground for the struggling GM industry and the laboratory for frustrated GM scientists" and that "GMOs are a threat to human health" (GMWatch, 2004; Makanya, 2004).

Other types of NGOs have also taken a stance against GMOs, including organisations for the protection of biodiversity (e.g. African Biodiversity Network, Tanzania Alliance for Biodiversity, Kenya Biodiversity Coalition, and African Centre for Biodiversity), organic farming networks (e.g. Kenya Organic Agriculture Network), and consumer protection agencies (e.g. Consumer Federation of Kenya and Consumer Information Network (CIN) of Kenya). For instance, CIN has portrayed biotech crops as a "time bomb" which regulatory authorities are not able to handle (Kameri-Mbote, 2012). Negative attitudes expressed by organisations for organic/niche farming could reflect that farmers which produce speciality crops for exportation might generally perceive GM crops as more risky due potential loss of market access and trade to Europe (further discussed in Chapter 19) (Paarlberg, 2014).

That being said, certain civil rights organisations approach biotech crops with a sense of precaution as opposed to a wholesale rejection. Such groups argue that GM crops are not a panacea and demand for more research to be conducted on the potential environmental and socio-economic impacts (e.g. Kenya National federation of Agricultural Producers, the Fresh Produce Exporters Association of Kenya, Cereal Growers Association and Tanzania Alliance of Biodiversity) (Kameri-Mbote, 2012; opinions expressed during Stakeholder survey). Additionally, groups like Organic Africa believe an integrated approach using organic, conventional and transgenic crops will provide the best results in terms of food security and business sustainability (finding from the Stakeholder perception survey).

9.4. Pro-GMO non-governmental organisations
Though this chapter mainly focuses on anti-GMO NGOs, it should be noted that pro-GMO groups also play a role in shaping the opinions of various stakeholders in Africa. Some argue that the attendance of various information and awareness meetings and seeing-is-believing tours hosted by such groups are mostly restricted to farmer elites who have the time, money and opportunity to participate (Schnurr & Mujabi-Mujuz, 2014). Thus, some question whether statements given by farmers in the aftermath of such meetings – which is often in the favour of widespread biotech crop adoption – truly represent the opinions of the East African farmer.

Pro-GMO groups include ISAAA, African Biotechnology Stakeholders Forum (ABSF), BIO-EARN, the Association for Strengthening Agricultural Research in East & Central Africa (ASARECA), the Organization for Transforming Initiated Technologies (OTIT) and Cereal Millers Association (CMA) of Kenya. For instance, the CMA of Kenya has spoken out against the Kenyan GMO labelling law (see Chapter 15) and the government's ban on GMO imports, stating that it prohibits the milling industry and could lead to increased food prices (ISAAA, 2012; Andae, 2016d)

9.5. Findings from the Stakeholder perception surveys
Note that the findings from the farmer surveys, including the importance of NGOs as a source of information on GM crops, will be presented in Chapter 24.

"Lobbying by anti-GMO advocates" was identified by stakeholders as one of the most important barriers to GM crop adoption in East Africa (i.e. 79.5% found it "important" or "very important") (Chapter 24, Table 24.17). This is consistent with a series of SWOT analyses (i.e. "Strength, Weaknesses, Opportunities and Threats") carried out by ISAAA, which identified active, vocal and strong anti-GMO organisations as one of the major "threats" to transgenic research and biotech adoption in Kenya, Uganda and Ethiopia (James, 2015).

Additionally, 55.2% of stakeholders found it "likely" or "very likely" that pressure from anti-GMO groups was part of the explanation for an apparent negative attitude change towards GMOs among East African governments (Chapter 24, Table 24.16). "Pressure from pro-GM advocates" was not considered as likely in explaining a potential governmental attitude change in favour of GMOs (i.e. 41% perceived it as "likely" or "very likely")(Chapter 24, Table 24.16). This suggests that anti-GMO groups have a higher level of influence than pro-GMO advocates, which could be explained by the level of impact that negatively angled information has on the receiving audience as compared to positively inclined information (Smale *et al.*, 2009).

56.4% of stakeholders further believed that anti-GMO groups had a "high level of influence" in swaying the opinions of the public and farmers in East Africa (Fig. 9.1), which was considered particularly true in the case of illiterates (evident through additional comments made by stakeholders). 30.8% perceived the influence as being "moderate", while 11.5% reported that anti-GMO groups had a "low level of influence" (1.3% did not have an opinion; not shown in Fig. 9.1) (Fig. 9.1). None of the stakeholders believed that such groups did not have any influence at all.

There were no significant differences in the perceived level of influence on the basis of nationality (Appendices 1, Table E.4). Of the stakeholders that perceived anti-GMO NGOs as having a "high level of influence", 27 were Kenyan (~61%), seven were Ugandan (~16), five were Tanzanian (~11%) and five were Ethiopian (~11%). Of those that found such groups to have a "moderate level of influence", 16 were Kenyan (~67%), three were Ugandan (12.5%), three were Ethiopian (12.5%) and two were Tanzanian (~8%) (Fig. 9.1). Of those that perceived the influence as being low, six were Kenyan (~67%), one was Ugandan (~11%), one was Tanzanian (~11%) and one was Ethiopian (~11%). One respondent (Tanzanian) did not have an opinion (not shown in Fig. 9.1).

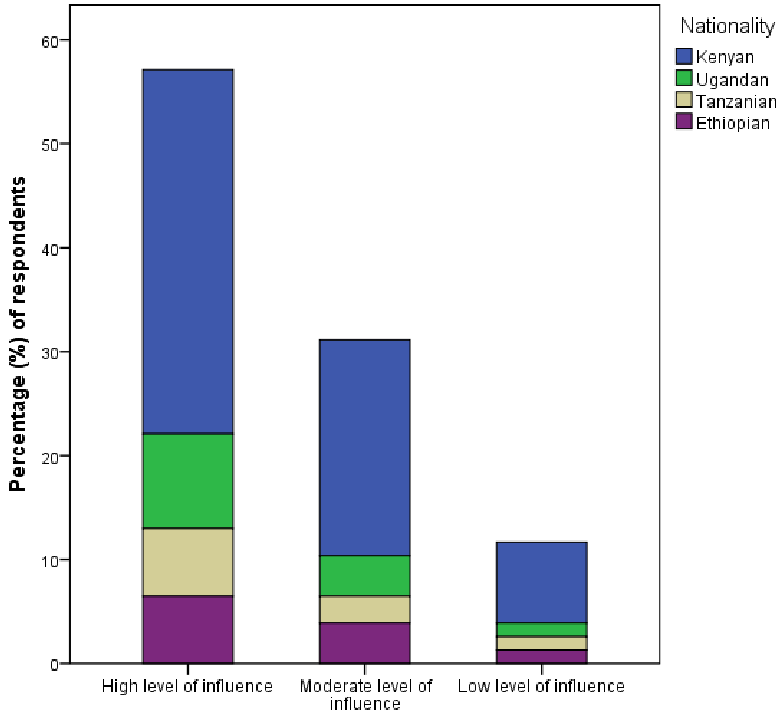


Figure 9.1. Level of influence by anti-GMO (genetically modified organisms) groups on public and farmer opinions of GMOs in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were no significant differences in the perceived level of influence on the basis of nationality ($p>0.05$). Response rate: 100% (78 out of 78 participants).

Interestingly, there were no significant differences in the perceived level of influence by anti-GMO groups on the basis of perception group or occupation (Appendices 1, Table E.4; Fig. E.5.5.1a+b). The lack of any statistical significance differences on the basis of nationality, perception group and occupation indicates that anti-GMO NGOs are present and influential in all of the study countries, and that stakeholders share a common understanding of the level of influence by such groups regardless of their general attitude towards GMOs or occupation.

However, there were significant differences on the basis of income level (Appendices 1, Table E.4). The majority of those with a moderate (US$400-599) and high (≥US$1000) income perceived anti-GMO groups as having a "high level of influence" (i.e. ~67% and 70%, respectively), while this opinion was not shared by any of the respondents earning less than US$200 (instead, ~67% of this income group perceived the influence as being "low") (Appendices 1, Fig. E.5.5.2). The majority (~55%) of those earning US$800-999 found the influence to be "moderate", while those earning between

US$600-799 divided themselves relatively equally between "high" and "moderate" level of influence (none perceived such groups as having "low influence") (Appendices 1, Fig. E.5.5.2).

The finding might suggest that those having moderate and high incomes more commonly perceive such groups as having a high level of influence compared to those with particularly low earnings (i.e. less than US$200). That being said, it is perhaps unlikely that income level *alone* should have an effect on how stakeholders perceive the level of influence by anti-GMO groups. Thus, it is perhaps likely that income level could reflect some other, underlying demographics such as educational level or occupational group, which might further have an influence on the participants' understanding of the activities and impacts of anti-GMO groups. However, as touched upon, no other significant demographic effects were found.

9.6. Concluding remarks

Non-governmental and civil society organisations are important for advocacy, raising awareness and promoting issues that concern the grassroots and politically weaker groups, as well as promoting a healthy level of scepticism. Indeed, issues related to biodiversity, ecological impacts, IPRs, concentration of power in the agricultural supply chain, food sovereignty, Farmers' Rights and so forth, *are* important. However, it is a sobering thought that so many anti-GMO campaigns spring out from countries in the Western world in which food availability and productivity is generally not a problem, and farmers only make up 1-2% of society, thus making the prospect of biotech crops less attractive as a mean of promoting food security (Paarlberg, 2014). Furthermore, it seems contradictory that certain anti-GMO groups would destroy the very thing that is supposed to test for the safety of such crops (e.g. confined field trials in the case of Golden Rice), and at times even falsely claiming that it was the work of farmers (e.g. Owens, 2011; Gosselin, 2013).

Thus, when such groups project their opinions of GMOs onto developing countries, and furthermore refrain from referring to studies indicating the safety of GM crops, one might question whether they have the best interest of the poor and rural farmer in mind. Consequently, some argue that the anti-GMO opposition leaves millions to starve due to irrational fears concerning transgenic crops (Zerbe, 2004). However exaggerated this argument may seem, a recent study did find that oppositions to GMOs create significant obstacles for developing nations, especially those in Sub-Saharan Africa, which could be costing these countries as much as US$1.5 trillion in foregone profit through 2050 (Giddings *et al*., 2016). In 2016, over 100 Nobel laureates signed a letter urging Greenpeace to stop its activities against biotech crops, including the campaign to prevent the introduction of Golden Rice (Support Precision Agriculture, 2016).

Chapter 10. Channels of Information on Genetically Modified Organisms (GMOs) among the East African Public, with a Special Emphasis on the Media

10.1. Channels of information on biotechnology and genetically modified organisms (GMOs)

Kagai (2011) found that the main source of information among farmers in the Trans-Nzoia county of Kenya was newspapers (43% of respondents), followed by extension officers (34%), radio (29%) and television (13%). In the case of consumers, the order was newspapers (32%), radio (20%), extension officers (27%) and television (13%). However, a study by Kimenju *et al*. (2011) found that radio was the main source of information on biotech crops among urban (63%) and rural (74%) consumers in Kenya, while newspapers was considered the second most important information channel among urban participants (56%), but much less so among rural consumers (26%). This could reflect the fact that the price of a printed paper is believed to restrict sales to the wealthier part of the population (DeRosier *et al*., 2015). However, sharing of newspapers or reading headlines for free is common (Obonyo, 2011; DeRosier *et al*., 2015). Contrary, rural respondents reported schools as an important source of information (63.5%) compared to only 35% of urban participants. In Eastern Kenya, agricultural researchers and extension services was considered important by rural consumers (53%), which is likely to reflect the presence of research stations such as KALRO.

Few studies have been conducted on the importance of various channels of information on GMOs in Uganda. However, Schnurr & Mujabi-Mujuz (2014) argues that the use of radio as a source of education on GM crops is restricted to the farmer alite, as it is largely communicated in English (Schnurr & Mujabi-Mujuz, 2014). In response to such arguments, a media representative from the study by Schnurr & Mujabi-Mujuz (2014) argued that it was too challenging to translate the terminology into the local languages. In Tanzania, the most important sources of information about GMOs among academia, regulatory authorities, service providers, NGOs, the media and farmers have been found to be workshops and meetings (48.4%), the news media (print and electronic) (36.2%), academic and research institutions (10.4%), and finally NGOs (5%) (United Republic of Tanzania, 2012).

10.2. The impact of the media on public opinion of agricultural biotechnology

Though the media does not necessarily directly determine or ever fully reflect public opinion, it is in a position to express relevant values and beliefs, as well as help confer legitimacy to or discredit particular groups by treating them as part of the mainstream or minority. By doing so, the media has the power to affect the perceptions that ultimately dominate collective discourse and decision-making. Indeed, studies have shown that the way in which biotechnology is covered in the media (e.g. Fig.10.1) can significantly impact the attitudes and opinions of different members of society, and thus influence the adoption rate of GM crops (Bonny, 2003; Bauer, 2005; McCluskey & Swinnen, 2004; Marks *et al*., 2007; Vilella-Vila & Costa-Font, 2008).

Figure 10.1. Various headlines about genetically modified organisms (GMOs) in some of East Africa's biggest news papers. From: Lyimo (2016) [The Citizen*,* Tanzania], Daily Nation (2016) [Kenya], Nabwiiso (2016) [East African Business Week], Dereje (2015) [The Ethiopian Herald, Ethiopia], The Capital (2015) [Ethiopia].

10.3. The frequency and nature of coverage of biotechnological issues and genetically modified (GM) crops

Relatively few studies have been conducted on the frequency and nature of the coverage of issues related to biotech crops in Africa and the East African region, as well as how such factors affect public and governmental opinion. Generally, the coverage of agri-biotechnological issues has been found be low on a continental scale (Waruru, 2015). Consistently, a study conducted between 2007 and 2009, found a low level of reporting of biotechnological issues in Kenyan newspapers, and furthermore that articles tended to be biased towards either the negative or positive (Lore *et al*., 2013). However, it should be noted that study was conducted at a point in which the enforcement of the National Biosafety Act of 2009 was still at its infancy and before the ban on GM imports was instated; both of which are cases likely to have gained traction in the media.

A study conducted by DeRosier *et al.* (2015) also found that the Kenyan media is not providing the audience with a balanced view of the perceived risks and benefits of GMOs, and that more news articles referred to the advantages rather than the potential demerits. However, when an article did sway towards the negative, a greater number of references to the possible risks were reported per article compared to the benefits.

10.4. Reasons for bias: Pre-determined standpoint, choice of reference/source, journalist-source-relationship, and the type of journalistic training

Predetermined standpoint. A study found that reporting on biotech crop issues by three major East African newspapers – the Kenyan the Daily Nation, the Ugandan the Daily Monitor and the Tanzanian the Citizen – often stemmed from predetermined standpoints (Randall, 2014). The Daily Nation expressed scepticism towards the regulatory capacity of the Kenyan government in managing import and trade of biotech food products and seeds (which according to the author could originate from the paper's opposition to the colonial government); the Daily Monitor appeared to consistently cover research-based stories, which indicated a positive attitude towards the advent of biotech crops; while the Citizen exhibited a more negative approach to GM crops, whereby the adoption of agricultural biotechnology was often questioned, including opinions from beyond the country's border. Thus, there did not appear to be a common theme concerning GMOs running through these selected East African newspapers (Randall, 2014).

Choice of reference/source and journalist-source-relationship. An interesting factor which may impact on the balance of a news story is the choice of reference(s)/source(s). Studies have found that the major source of information in Kenyan newspapers consists of scientists and governmental officials, while the voice of farmers remains more or less muted (Masood, 2005; Lore *et al.*, 2013). This finding is consistent with DeRosier *et al*. (2015) who found that Kenyan newspapers cited governmental representatives most often, followed by scientists and NGOs. When relying on scientists for their reporting, the article was more likely to report benefits than when using NGOs, people from the government and businesses – and vice versa (DeRosier *et al*., 2015). Additionally, studies have found that information about biotechnology provided by governments, the media, the industry and scientists confuse rather than enlighten consumers (e.g. Hossain & Onyango, 2004; Costa-Font *et al*., 2008).

The choice of reference may partly be influenced by a predetermined bias, as seen in the case of the three major East African newspapers above. However, there is currently little knowledge on how East African journalists seek out information – whether through easy-access, internet-based searchers or more in-depth methods.

Furthermore, the relationship between the journalist and the source is dynamic and complex, and at times affected by power relations and personal agendas (Randall, 2014). Consequently, even though the ultimate decision on how to frame the story lies in the hands of the journalist, the dynamics of the source-journalist-relationship is likely to affect how the story is conveyed (Randall, 2014). For instance, a media representative who participated in the present survey said that multinational corporations had been known to bribe journalists to report stories that were in favour of the companies and of GMOs.

Journalistic training. Biased or inadequate news coverage of agricultural biotechnology may also reflect the nature of the journalistic training the reporter exhibits (Lugalambi *et al*., 2011; DeRosier *et al*., 2015). For instance, some journalists may not possess the appropriate background knowledge to understand and report on scientific matters in an appropriate manner (DeRosier *et al*., 2015). For instance, Dr. Faith Nguthi has previously stated that the use of negative or misleading imagery limits public understanding (e.g. using an image of a tomato being injected with a substance to explain GM technology, which was how many of the surveyed farmers understood the concept of GMOs), while Bibiana Iraki (also from ISAAA *Afri*Center) has underlined the importance of reducing the use of conflict in news reporting on biotech issues (ISAAA, 2016h).

In an attempt to address such issues, certain organisations and initiatives provide training for journalist in conveying biotechnological sciences. For instance, Biosciences for Farming in Africa (B4FA) has provided professional training to Tanzanian and Ugandan journalists on the science of plant breeding (as cited by DeRosier *et al*., 2015); COMESA-ACTESA (Alliance for Commodity Trade in East and Southern Africa), the Ministry of Environment and Forest in Ethiopia, ISAAA *Afri*Center and the Open Forum on Agricultural Biotechnology (OFAB) recently organised a biotechnology and biosaftey communication training workshop for over 30 media representatives from a range of countries, including Ethiopia, Kenya and Uganda (ISAAA, 2017c); UBIC has made plans to engage more with the media as a way of increasing public awareness (ISAAA, 2017b); while ISAAA has arranged Scientists-Journalist Pairing Programs and hosted a capacity building meeting for editors from Kenyan TV stations, radio and newspapers to update them on the current status of biotechnology research in Kenya (ISAAA, 2016h). During this meeting, the Secretary General of the Editors Guild, Mr. Hassan Kulundu, stressed the importance of scientists avoiding the use of jargon when conveyeing their research to the media, which underlines the importance of also educating researchers on how to communicate science in an easy-to-grasp and engaging manner. Indeed, a study covering science communication in Sub-Saharan Africa found that there is a common understanding of the importance of science communication for the further development of the region, but that a pattern of distrust had developed between scientists and journalists (Outram, 2010).

10.5. Findings from the Stakeholder perception survey

Note that the findings from the farmer surveys, including the most important sources of information on GMOs and their potential impact on farmer opinions, will be presented in Chapter 24.

The nature of reporting on GMOs. An equal number of stakeholders found the way in which information about GMOs were communicated to the East African public as being “biased towards the positive” (29.5%), “biased towards the negative” (29.5%) and “balanced” (29.5%) (Fig. 10.2). Additionally, 5.1% considered the information as being biased towards the “positive and negative” (note that this was not included as a response alternative in the questionnaire, but added by participants).

There were no significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that perceived the information as being “biased towards the positive”, 16 were Kenyan (~70%), three were Ugandan (~13%), two were Tanzanian (~9%) and two were Ethiopian (~9%) (Fig. 10.2). Of those that considered it as being “biased towards the negative”, 14 were Kenyan (~61%), four were Ethiopian (~17%), three were Ugandan (~13%) and two were Tanzanian (~9%) (Fig. 10.2). Of the stakeholders that perceived the information as being “balanced”, 15 were Kenyan (~65%), four were Ugandan (~17%), two were Tanzanian (~9%) and two were Ethiopian (~9%) (Fig. 10.2). Of those that found it “biased towards the positive and negative”, two were Kenyan (50%), one was Ugandan (25%) and one was Tanzanian (25%) (Fig. 10.2). Finally, four respondents “did not know”, of which two were Tanzanian (50%), one was Kenyan (25%) and one was Ethiopian (25%), while one participant (Kenyan) did not give a reply (not shown in Fig. 10.2).

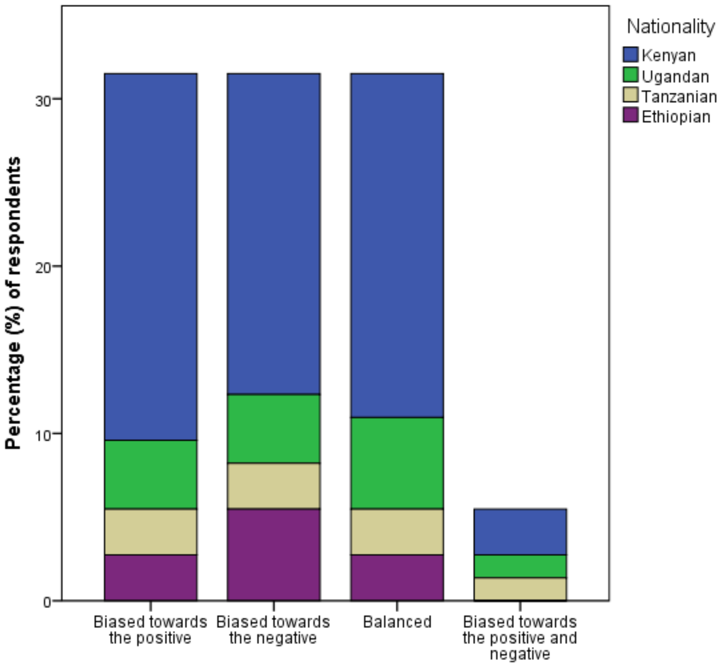


Figure 10.2. Balance of information about genetically modified organisms (GMOs) communicated to the East African public as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were no significant differences in the perceived balance of information on the basis of nationality (p>0.05). Response rate: ~99% (77 out of 78 participants).

In other words, stakeholders across nationalities perceived the information as being biased, which is consistent with Lore *et al*. (2013) and DeRosier *et al.* (2015). However, there were significant differences in the perceived balance of information on the basis of perception group (PG) and occupation (Appendices 1, Table E.4). The majority of respondents from PG1 (~72%) and civil servants employed in an NGO (50%) found the information to be “biased towards the positive”, while stakeholders from PG4 and agricultural researchers divided themselves relatively evenly between perceiving the information as being “negatively biased” and as being “balanced” (Appendices 1, Table E.5.6). Additionally, ~73% of extension workers considered the information as being “balanced towards the negative” (Appendices 1, Table E.5.6). Thus, it appears as if the perceived balance of communication could be somewhat influenced by – or biased on the basis of— the respondents’ general attitude towards GMOs and occupation.

The importance of balanced and objective reporting on GMOs. 71.8% of stakeholders considered the “polarised debate presented in the media” as an “important” or “very important” barrier to GM crop adoption (Chapter 24, Table 24.17). Consequently, 91% of stakeholders considered “objective and factual media coverage” as an “important” or “very important” measure to allow for successful adoption (Chapter 24, Table 24.18), while 89.7% considered it a “likely” or “very likely” way of correcting some of the common public misconceptions associated with the technology (Chapter 24, Table 24.15).

10.6. Concluding remarks

By representing the middle man between various stakeholders – the public, farmers, scientists, biotech companies, and policy and decision-makers – the media plays an important role in facilitating communication, as well as increasing awareness and knowledge of biotechnology. However, journalistic reporting on biotech issues have displayed a tendency of low and/or biased coverage. Thus, there is a need to establish policies and guidelines, as well as capacity building efforts, to enable factual, unbiased, objective and adequate coverage of news related to science and technology, without necessarily linking the story to some controversy as a way of provoking interest. Additionally, it is essential to build trust between the media and the scientific community, for instance through initiatives such as Journalist-Scientists Pairing Programs.

Part D. Biotech Crops and Socio-Economic Considerations in East Africa

Chapter 11. Biotech Crops and Socio-Economic Considerations

11.1. Introduction

The introduction of any novel technology can have wide-spreading impacts on society and, conversely, the components of society may affect the adoption of the technology itself. Consequently, the GMO debate extends much farther than the mere scientific and technological aspects. Additionally, when food – which forms a fundamental part of human life – is put into the equation, strong emotional forces are bound to be at play.

Some argue that GMOs exhibit certain characteristics that make the social impact even more substantial and far-reaching – in time and space – than with conventional breeding, and as a result are unsustainable in the economic and social context (Marsden, 1999; Jensen & Sandoe, 2002). For instance, Daño (2007) argues that the manipulation of life forms and biological processes, as well as the long-term socio-economic impacts, are unique to biotechnology. However, have humans not manipulated species, life forms and – perhaps unknowingly – biological processes since the dawn of domestication? Or has the fact that we now can do more precise changes in a shorter amount of time created new ethical dilemmas and higher risks compared to the more time-consuming and unpredictable process of conventional breeding?

Either way, biotechnology *does* open up a new world of unknown perspectives and uncertainties, and estimating potential risks or bi-effects can prove challenging, especially when considering socio-economic factors.

What socio-economic issues may arise as a result of the introduction of biotech crops in the East African society? Are any of them justifiable or even measurable in a scientific context? And if so, how can socio-economic considerations best be implemented in the regulatory systems governing biosafety and biotechnology?

11.2. Definition of socio-economic considerations and overview of part D

La Vina & Fransen (2004) attempted to define socio-economic considerations (SECs) in the context of biotechnology:

"[…] Taking into account a broad spectrum of concerns about the actual and potential consequences of biotechnology, such as impacts on farmers' incomes and welfare, cultural practices, community well-being, traditional crops and varieties, domestic science and technology, rural employment, trade and competition, the role of transnational corporations, indigenous people, food security, ethics and religion, consumer benefits, and ideas about agriculture, technology and society".

For the purpose of this thesis, the following socio-economic factors will be considered: (i) ethics and religion; (ii) Big Business, Intellectual Property Rights and Farmers' Rights; (iii) gender equality; (iv) consumer choice; (v) distribution of benefits and economic equality; (vi) rural employment; (vii) competition; (viii) market and trade; (ix) public and private sector investment; and (x) distribution, accessibility and infrastructural short-comings. For convenience, the socio-economic factors will be grouped into "Part I: Ethical, Social and Cultural Considerations" (i-iv) and "Part II: Economic Considerations" (v—x).

Subsequently, Chapter 22 will take a small look back in history to the Green Revolution in an attempt to provide some indication of what one might expect from a potential Green Revolution 2.0. Finally, Chapter 23 will consider the inclusion of SECs in selected international and East African regulatory frameworks; the potential benefits and constraints of factoring in such considerations; and some tools, methods and recommendations on how to best assess and implement SECs in regulatory decision-making.

Part I. Ethical, Cultural and Social Considerations

Chapter 12. Gene Technology, Ethics and Religion

Genetic modification involves the manipulation of life forms and biological processes which challenges some fundamental human values and raises some ethical questions, perhaps even more so on a continent where religion and at times superstition can represent a strong societal force (Pew Research Center, 2015; Mulemi & Ndolo, 2014). Are we reducing nature to a simple object of human manipulation? Are we promoting ourselves to a God-like status by doing so (Verhey, 1995; Warner, 2001)? Does genetic modification conflict with what was created in the image of God? What if transgenes were sourced from religiously or ethically unacceptable organisms; will products still be halal, haram or vegan? Is it ethical justifiable *not* to explore the use of biotechnology if it has beneficial effects on food security, poverty and the environment? Or does nature know what is right and wrong when it comes to food?

As touched upon in Chapter 9, the motivational and ideological forces of many anti-GMO advocates may originate from a religious, ecological, and/or animal and human rights activist standpoint (e.g. Greenpeace, Oxfam, Friends of the Earth, and the Jesuit Centre for Theological Reflection). Parts of the scientific community has a tendency to dismiss religious and ideological viewpoints as being irrational and emotionally driven, and argues that the debate should be based on rational thinking and empirical knowledge (BBC, 2015; Hielscher *et al*., 2016). However, science and technology is seldom neutral, and researchers and academics are often driven by strong personal beliefs and values (Goldsmith, 2000; Heiene, 2001; Gavroglu, 2009). Besides, if emotional, religious and ethical principles were to be dismissed all together, then the time and resources put into R&D may all be in vain – what is the point of releasing a particular crop variety if it is rejected due to religious misgivings? Or what if religion actually makes consumers and farmers more optimistic about the advent of biotechnology, as demonstrated in a study by Scheitle (2005)? Or is religion simply not a strong enough societal force to influence people's perceptions of GM foods?

12.1. Biotech crops and the Christian faith

Christianity, with its multitude of branches (Catholic, Anglican/Church of England, Protestant, Orthodox, etc.), is the largest religion in East Africa, followed by the Islamic faith (ARDA, s.a.).

The influential Catholic organisation the Pontifical Academy of Science (PAS) has previously concluded that biotech crops "offer food safety and security, better health and environmental sustainability"; a declaration which has been considered "the Vatican's blessing of GM crops" (New Scientist, 2009). Recently, a Nigerian Catholic Archbishop supported the safe usage of agricultural biotechnology as a way of meeting the challenges faced by the agricultural sector (ISAAA, 2017d). Still, there are several anti-GMO groups within the Catholic Church, for instance the Columban Missionaries (Teague, 2013).

The Church of England (CofE) argues that "human discovery and invention can be thought of as resulting from the exercise of God-given powers of mind and reason", i.e. scientists are using the abilities bestowed on them by God to better the lives of humans and facilitate sustainable development (Church of England, 1999). CofE further underlines the importance of proper labelling to allow for consumer choice (Church of England, 1999). However, the different branches within the Anglican Church, some of which have cultural ties to certain former British colonies (including Kenya and Uganda), exhibit different opinions on GM food (Omobowale *et al*., 2009). For instance, the former Anglican Archbishop of Cape Town argued that biotech crops are not considered safe for human consumption or for the African farming systems, and that the technology would lead to reduced job opportunities, further dependence on countries of the Northern hemisphere and loss of biodiversity (Mathys, 2004).

The Conference of European Churches (CEC) has gone head-to-head against the World Council of Churches (WCC) in the debate on GMOs (Omobowale *et al*., 2009). CEC supports the adoption of agricultural biotechnology, presupposing that it takes into consideration the “genuine concerns for everything created by God”, i.e. by respecting ethical and moral limits (Conference of European Churches, 2001). The WCC on the other hand, dismiss genetic modification of plants as being unethical from a Christian perspective (World Council of Churches, 2005).

12.2. Biotech crops and the Islamic faith

The rulings on genetics and biotechnology appear to be rather similar for the two major Islamic branches Sunni and Shia (Omobowale *et al*., 2009). Groups of Muslim intellectuals have previously concluded that there are no laws within the Quran which prohibits genetic engineering of plants and animals (ISLAM Set, 1998). In fact, the Islamic country Egypt was among the first African countries to allow for commercialised events (however, plantings were later discontinued, though this was not due to religious misgivings; Chapter 1, section 1.2) (Omobowale *et al*., 2009; Adenle, 2011). Furthermore, the world’s largest Muslim country, Indonesia, is actively engaged in the genetic manipulation of plants at the R&D stage (Rahayu, 2015). However, Muslim academics do remain divided on the topic, as apparent in a letter to the British government from the head of the Islamic Medical Association, Dr. Majid Katme (Katme, 2006; Whitaker, 2007). Katme argues that, according to the Quran, God created everything perfect and man has no right to manipulate any of his creations (Katme, 2006).

12.3. The influence of religious beliefs on attitudes towards genetically modified (GM) crops

How big of an influence is faith and religion on public attitudes towards biotech crops? Even when faced with famine and starvation, will religion have the final say? Djamchid Assadi, a Professor of Marketing and Communication at the American University of Paris, argues that religion has become less influential in contemporary secular societies and that individualism is becoming the prevailing philosophy of life (Assadi, 2003). Thus, rather than turning to religion for answers, Omobowale *et al.* (2009) argues that it is more down to the individual opinion of the African consumer, and perhaps more so for those facing hunger, poverty and food insecurity. Still, a study by Schnurr & Mujabi-Mujuzi (2014) found that some Ugandan farmers expressed religious concerns associated with GM crops; one farmer stated that “I prefer the old methods of breeding, because when God did create, he had no regrets. But the new system worries us”.

12.4. Findings from the Stakeholder and Farmer perception surveys

Stakeholder survey

Note that it was not possible to discern any potential differences in perceptions on the basis of faith as all but two stakeholders were Christians (Chapter 24, Table 24.5).
59.0% of stakeholders considered religious beliefs as “not influential”, 16.7% “somewhat influential”, 9.0% “influential” and 12.8% “very influential” on their acceptance of GM food products (2.6% did not respond; not shown in Fig. 12.1) (Fig. 12.1).

There were no significant differences in the level of religious influence on the basis of nationality (Appendices 1, Table E.4). Of those that perceived religious beliefs as “not influential”, 20 were Kenyan (~54%), seven were Ugandan (~19%), six were Ethiopian (~16%) and four were Tanzanian (~15%) (Fig. 12.1). Of those that perceived it as “somewhat influential”, eight were Kenyan (~62%), two were Ugandan (~15%), two were Tanzanian (~15%) and one was Ethiopian (~8%). Of the stakeholders that considered religious beliefs “influential”, four were Kenyan (~57%), two were Ugandan (~29%) and one was Ethiopian (~14%). Finally, of the stakeholders that found religion “very influential”, six were Kenyan (60%), three were Tanzanian (30%) and one was Ethiopian (10%) (Fig. 12.1). Two participants, of whom both were Kenyan, did not reply (not shown in Fig. 12.1).

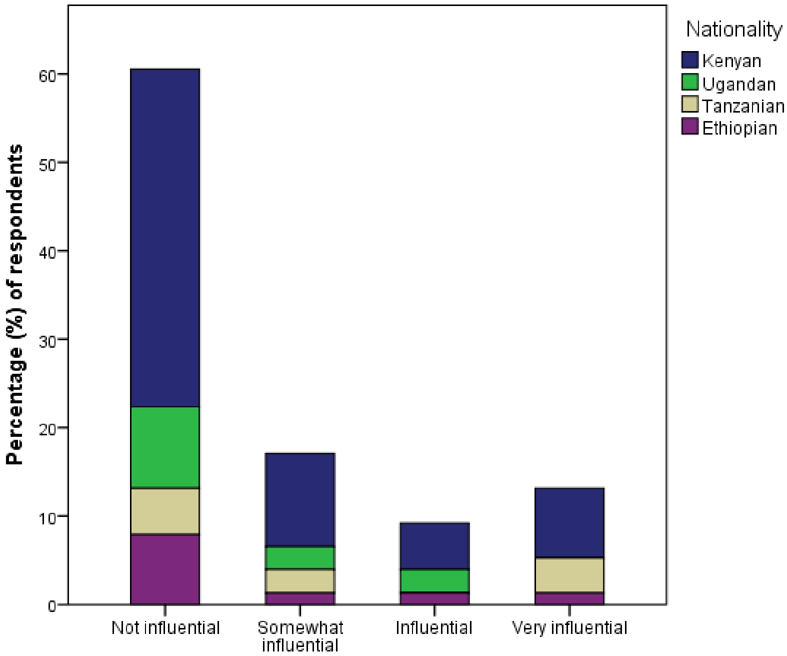


Figure 12.1. Level of influence of religious beliefs on acceptance of genetically modified (GM) food products among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were no significant differences in the level of influence of religious beliefs on the basis of nationality (p>0.05). Response rate: ~97% (76 out of 78 participants).

Additionally, 61.5% of stakeholders were “not concerned” or only “somewhat concerned” about potential religious/cultural implications associated with the adoption of biotech crops (e.g. sourcing of genes from culturally or religiously unacceptable organisms) (Chapter 24, Table 24.12).

Farmer surveys

On average, ~73% of Kenyan, Ugandan and Tanzanian farmers perceived religious beliefs as being "not influential" on their acceptance of GM crops, while ~16% found religious beliefs "somewhat influential", ~8% "influential" and ~3% "very influential" (Table 12.1).

Table 12.1. Level of influence of religious beliefs on the acceptance of genetically modified (GM) crops among Kenyan, Ugandan and Tanzanian farmers; in % and [number] of respondents.

	Not influential	Somewhat influential	Influential	Very influential
Kenya [1108]	64.0 [710]	29.5 [327]	4.1 [46]	2.2 [25]
Uganda [142]	60.5 [86]	13.3 [19]	19.0 [27]	7.0 [10]
Tanzania [804]	93.2 [750]	6.4 [52]	0.0 [2]	0.0 [0]
Average/total [2054]	~73 [1546]	~16 [398]	~8 [75]	~3 [35]

Response rate Kenya: ~98% (1108 out of 1127 participants).
Response rate Uganda: 100% (142 out of 142 participants).
Response rate Tanzania: ~100% (804 out of 805 participants).
Total response rate: ~99% (2054 out of 2074 participants).

Leading on from this, ~35%, ~37% and ~88% of Ugandan, Kenyan and Tanzanian farmers said they were "not concerned" about potential religious/cultural misgivings associated with GM crops (Chapter 24, Table 24.8, 24.6 and 24.10, respectively). Contrary, ~1%, 31% and ~48% of Tanzanian, Ugandan and Kenyan farmers were "concerned" or "very concerned" (Chapter 24, Table 24.10, 24.8 and 24.6, respectively). Several farmers argued that GM crop adoption was merely considered from a business point-of-view, while others had religious concerns such as sourcing of genes from ethically unacceptable species (e.g. pigs in the case of the Islamic faith) and as a result did not support commercialisation of the technology.

There were significant differences in the level of religious influence and religious/cultural concerns on the basis of geographical location (i.e. within and between countries) (Appendices 1, Appendix D.2, D.6-D.8). Such findings could possibly reflect differences in the effect that the Christian and Islamic faith may have on perceptions and acceptance of GM crops. For instance, one could hypothesise that Muslims have less religious misgivings associated with transgenics, which could help explain the low levels of religious influence and concerns recorded in Tanzania (i.e. where the highest level of Muslim farmers was recorded; Chapter 24, Table 24.3). However, it was not possible to investigate such relationships further, as the variation upon which to estimate the correlation was too small (i.e. only two of the Tanzanian farmers considered religious beliefs "influential" or "very influential", while only 12 participants found religious/cultural concerns either "concerning" or "very concerning"). Similarly, such investigations could not be carried out among Kenyan and Ugandan farmers as the number of Muslims was too low (i.e. only five and 14 farmers in the Kenyan and Ugandan survey, respectively; Chapter 24, Table 24.1 and 24.2, respectively).

However, the effect of religion on impressions of GM crops was investigated among Tanzanian farmers, but no significant correlations were found. Thus, it is perhaps more likely that there are other explanatory factors for the observed difference in the level of religious influence and concerns (further explored in Chapter 24).

12.5. Concluding remarks

It is challenging to tease apart any clear guidelines on how Muslims and Christians should position themselves in the GMO debate on the basis of their faith (Omobowale *et al*., 2009). Indeed, perceptions among religious leaders and organisations appear as divided on the matter of GM crops as any other societal group. Furthermore, the data obtained from the perception studies indicate that religious beliefs have relatively low level of influence on the perceptions and acceptance of GM crops and food products among farmer and other stakeholders in East Africa, which appear more in line with what is suggested by Assadi (2003) and Omobowale *et al.* (2009). Instead, the business aspect of GM crop adoption seemed to be weighed more heavily.

That being said, the present study did not allow for a thorough, statistical investigation of the relationship between religious faith and the opinions expressed by farmers and other stakeholders, thus further investigations are needed. Furthermore, certain farmers and farmer groups did express religious misgiving associated with the use of biotechnology, which is consistent with Schnurr & Mujabi-Mujuzi (2014). This goes to show that ethical and religious concerns are present in some East African communities and could possibly represent a barrier to biotech crop adoption. Consequently, it might be necessary to evaluate the level of religious concern on a region-by-region and/or case-by-case basis. Furthermore, effort to educate religious leaders on the topic may be an important measure seeing as they have the ability to reach a wide audience, including the rural poor. For instance, UBIC recently organised a tour to the National Crop Resource Research Institute in Uganda for representatives from the Catholic, Orthodox, Adventist, Islamic and Pentecostal faiths (ISAAA, 2017e).

Chapter 13. Big Business, Intellectual Property Rights and Farmers' Rights

13.1. Introduction: The role of private multinationals

The agricultural market and research sector – whether it is concerning the seed market, agricultural chemicals or biotech crop varieties – is dominated by a few, large and private multinational companies – such as Monsanto (USA), DuPont (USA), Syngenta (Switzerland), Bayer (Germany), BASF (Germany), Groupe Limagrain (France) and Dow AgroSciences (USA) (Fig. 13.1) (Castro, 2015) – which are becoming increasingly bigger (Box 13.1). To put things in perspective: In 2006, Monsanto invested 10% of its total revenue to R&D within agricultural biotechnology, which accounted for US$ 550 million. In comparison, CGIAR invested approximately US$450 million in agricultural R&D, whereby only a small portion went towards agri-biotechnology (Virgin *et al*., 2007).

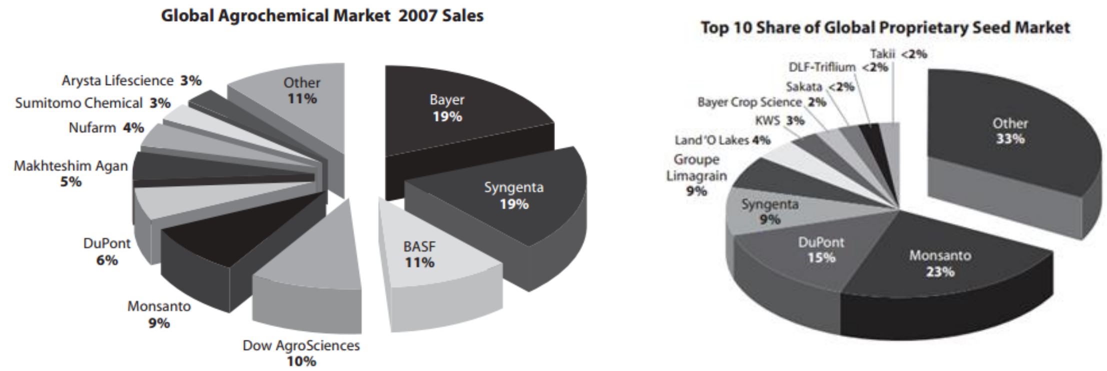


Figure 13.1. Market share of the global agrochemical market (pie chart, left) and global proprietary seed market (pie chart, right) by the top 10 private multinational companies in 2007. Similar figures from recent years were not obtainable, thus the current market share will be somewhat different, but the overall trend is likely to be similar. Figure from: ECT Group, 2008.

Box 13.1. Mergers of private multinationals pose problems for farmers? Currently, several mergers are being tabled, including between DuPont and Dow Chemical Company, a planned takeover of Monsanto by Bayer, and the previously mentioned takeover of Syngenta by ChemChina. Some worry that such mergers will increase the price of seeds and planting materials further, while decreasing the price of commodities and crops (Picker & de la Merced, 2015; Picker *et al*., 2016).

Many multinationals have increased their investment within the agricultural sector in the developing world, including biotech crop projects (FAO, 2012b; Chapter 4, Table 4.1). This has caused some to question the ulterior motives of such companies – why would multinational corporations want to invest in seemingly unprofitable pro-poor technologies and in a market where most farms are small-scale and subsistence? Indeed, the promotion of biotech crops as pro-poor and environmentally sustainable – an image believed to have been partly created by the biotechnology industry (Glover, 2009; 2010) – seems contradictory considering that most commercially available transgenic crops have been developed with large-scale, industrialised farming in mind (Elliott & Madan, 2016).

Thus, some describe investments by transnational companies in developing countries as a "Trojan horse" for expanding market access, gaining control of the seed market, promoting a transition from subsistence to commercially-driven farming, and to create long-term dependence on the technology (e.g. Box 13.2) (Zerbe, 2004; Cooke & Downie, 2010; Glover, 2010). As a consequence, distrust by various stakeholders towards the private sector has been identified as one of the obstacles to biotech crop adoption in Sub-Saharan Africa (Ezezika *et al*., 2012).

Much of the debate on who really owns the agricultural supply chain – or even nature herself – has been centred on Intellectual Property Rights (IPRs), which is believed to concentrate ownership of agricultural resources and determine which products become available. Thus, IPRs will be the focus of the remainder of this section. However, it should be recognised that several other issues contribute to the debate, including continuing globalisation and liberalisation of markets and the seed industry, shifts in the political economy of agriculture, ownership of genetic resources, and access to genetic resources and the equal sharing of benefits that arise from such resources (e.g. the international agreement of the Nagoya Protocol on Access to Genetic Resources and Equitable Sharing under the CBD) (Chambers *et al*., 2014).

Box 13.2. Monsanto – "The Big Bad Wolf"? Monsanto has by some, especially anti-GMO NGOs and farmers' movements coalitions, been appointed the "big, bad wolf" (e.g. AFP, 2015). Some speculate that, following the European moratorium on GM crops in 1998 (Chapter 8, section 8.1), Monsanto went looking for a new market for its products, as well as a way to improve the reputation of biotech crops (Glover, 2010). Thus, Monsanto turned to the developing world – or so it is argued by certain authors (e.g. Schurman, 2004; Glover, 2007a, 2007b, 2007c, 2010; Schurman & Munro, 2006; Newell, 2008; Scoones, 2008).

Between 1999 and 2002, Monsanto established the Technology Cooperation Programme whereby certain pieces of the company's intellectual properties were licensed for non-commercial applications relevant to the developing world (Glover, 2010). For instance, in year 2000, Monsanto shared its working draft of the rice genome with the International Rice Genome Sequencing Project, as well as sharing proprietary technology with scientists working on Golden Rice (Monsanto Company, 2000a, b). Concurrently, Monsanto initiated the Smallholder Programme in order to provide poor farmers with a "package" consisting of agricultural technologies and extension support (Glover, 2010). Additionally, Monsanto started to fund third-party research which proposedly produced a range of economic studies which claimed significant benefits of GM adoption in the developing world, as well as promoting biotech crops as safe and environmentally friendly (Glover 2007b; Glover, 2010).

Glover (2010) argues that all of the above were initiated as part of a deliberate strategy to expand the company's market in the developing world, to improve the reputation of biotech crops, and to encourage the transition from subsistence to commercial farming. Monsanto itself has stated that the company "has a track record of sharing knowledge and technologies with the public sector" – at reasonable costs and quantities – and that such initiatives stem from a "natural human value to share" while not conflicting directly with the company's commercial pursuit (Horsch & Montgomery, 2004).

13.2. Socio-economic impacts associated with Intellectual Property Rights

New technologies are often delivered with IPRs which enable companies exclusive rights to the product (e.g. claiming control of seeds), as well as the opportunity to impose royalty and technology fees to recoup some of their investments (Lambrecht, 2001; ASSAF, 2010). It has been argued that proprietary control contribute to several socio-economic impacts, including (i) ethical concerns, such as the patentability of life (Mayer, 2003); (ii) monopoly control that the transnational companies exercise on the price of biotech seeds (Virgin *et al*., 2007); (iii) negative impacts on Farmers' Rights (Box 13.3), food sovereignty, and traditional agricultural practices, knowledge and crop varieties (Virgin *et al*., 2007); (iv) exacerbation of socio-economic injustice (Mayer, 2003; Virgin *et al*., 2007); and (v) impediment of the free flow of information, knowledge, genetic materials and technological innovations needed by public institutions to deliver pro-poor technologies (Fransen *et al*., 2005; Daño, 2007; Fischer *et al*., 2015).

For instance, saving and exchanging seeds and planting material has been practiced by East African farmers for centuries and has contributed to greater genetic diversity, flexibility and resilience of farming systems (Virgin *et al*., 2007). Consequently, any limitation to such practices could be considered a violation of Farmers' Rights and long-standing cultural practices (e.g. cultural uses of biodiversity, traditional conservation and cropping practice, and the indigenous knowledge systems), and has been proposed to pose a threat to entire farming communities and long-term food security due to loss of genetic diversity (Fransen *et al*., 2005; Daño, 2007; Azadi *et al*., 2011).

Most commonly, farmers have to sign a contract whereby they pledge not to save, replant or sell seeds or planting material obtained from a proprietary GM crop variety (and in some cases refrain from purchasing agrochemicals from other companies) (Campbell, 1998; Lambrecht, 2011; Monsanto Company, s.a.-c). However, many smallholder farmers simply cannot afford buying new seeds every season or find themselves in greater debt if being charged due to violation of the contract (Virgin *et al*., 2007). Consequently, the access to proprietary protected transgenic varieties may become limited to elite farmers with the effect of exacerbating socio-economic inequality (further discussed in Chapter 16) (ASSAF, 2010).

Box 13.3. What are Farmers' Rights and how are they protected? The debate on Farmers' Rights usually revolve around the right to save and exchange seeds and planting material, but the concept also includes, amongst others, (i) protection of traditional knowledge; (ii) equal sharing of the benefits that arise from the use of genetic resources; and (iii) a farmer's right to take part in the decision-making concerning conservation and sustainable use of such resources (Naluwairo, 2006). Some of these rights are enclosed in the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) which is signed and ratified by all study countries (FAO, 2009; FAO, 2017). Additionally, the AU Model Law for the Protection of the Rights of Local Communities, Farmers and Breeders and for Regulation of Access to Biological Resources also recognises farmers' and communities' rights over plant genetic resources, in addition to traditional knowledge, innovation and practices (Organisation of African Unity, 2000; IIED, s.a.).

The idea of Farmers' Rights is relatively new to many East African stakeholders, including policymakers that are responsible for implementing such rights (Naluwairo, 2006). Consequently, the concept may appear rather unclear and diffuse, which has resulted in a lack of efficient mechanisms for putting Farmers' Rights into practice (Naluwairo, 2006). Furthermore, many countries find it difficult to co-align the regulations established by international trade agreements (e.g. the TRIPS Agreement) with that of the ITPGRFA and protection of Farmers' Rights (Daño, 2007).

13.3. Are East African farmers already tied into Intellectual Property Rights frameworks?

The proprietary seed market accounts for over 80% of commercially-sold seeds, be it conventional or GM, and many concerns associated with biotech crops and IPRs are considered similar to those associated with hybrids seeds and elite cultivars (though the IPRs of GM crop varieties are considered to provide stronger protection) (Donnenwirth *et al*., 2004; Virgin *et al*., 2007; ETC Group, 2008). Consequently, some argue that many East African farmers already have to abide to the rules of seed stewardship due to their dependence on improved varieties, and that the discussion on IPRs should revolve around the companies and institutions that hold the proprietary rights rather than the technology itself (an argument supported by Dr. Oduor).

Studies have previously indicated a relatively low adoption level and rate of improved varieties, especially in remote and marginal areas (Doss *et al*., 2003; Virgin *et al*., 2007). In 1999, hybrid maize varieties were planted on only 4%, 6% and 5% of the total areas dedicated to maize in Ethiopia, Tanzania and Uganda, respectively (CIMMYT Maize Research Impacts Survey 1998/1999; as cited by Virgin *et al*., 2007). In Kenya, 65% of maize areas were found to be dedicated to hybrid varieties in 1999 (CIMMYT Maize Research Impacts Survey 1998/1999; as cited by Virgin *et al*., 2007). Virgin *et al.* (2007) further cite a Daily News report from 2002 which found that less than 10% of Tanzanian farmers used hybrid maize seeds. In Uganda, 11% of land areas have been found to be dedicated to cultivation of improved varieties (Virgin *et al*., 2007). However, the adoption level of hybrid maize has been shown to be relatively high in certain areas, including the Lake Victoria Basin whereby 60% of farmers were found to plant up to 60% improved varieties (Sserunkuuma, 2004).

Since then, data obtained from FAO show that the percentage of improved seeds in Kenya was ~27-31% in 2005, and that such seeds were used by ~32-34% of households (percentage depends on farm size). No data on the percentage of improved seeds was available in Ethiopia, but ~23-31% of households used such seeds in 2012. In Uganda, improved seeds constituted 7-25% and were employed by 15-31% of households in 2012. No data was available for Tanzania in terms of percentage of households which employ improved seeds, but improved seeds amounted to 23-26% in 2009 (FAO, s.a.-c). Additionally, a recent study found that the average adoption rate of hybrid maize seeds was 45% in Kenya and Tanzania, and 43% in Uganda (Marechera *et al*., 2016).

Thus, it appears that the level and rate of adoption of improved seeds and varieties have increased in recent years, at least for hybrid maize. Still, the notion that all East African farmers are tied into the proprietary seed market may be unfound. It further suggests that increased delivery of improved and elite non-GM material could have beneficial impacts on productivity, yield and food security.

13.4. The importance of Intellectual Property Rights for foreign investment in agri-biotech projects in developing countries

It is important to recognise that IPRs help promote research within the private sector and provides an incentive for companies to invest in a foreign market where the returnable profit may be small (Barton, 2003; Basu & Qaim, 2007; Kerle, 2007). Thus, inadequate protection of IPRs and poor legal systems may discourage foreign investors, which may prevent East African countries from reaping the potential benefits of a technology (Paarlberg, 2001; Adenle, 2011; Chambers *et al*., 2014). Furthermore, weak IP systems can be particularly challenging for public-private partnerships (PPPs) in the case whereby the partners involved have different IPR arrangements (see Chapter 20 for more information about PPPs) (Kerle, 2007; Chambers *et al*., 2014). For example, unresolved issues concerning IPRs were believed to slow down the progress of the Insect Resistant Maize for Africa (IRMA) project in Kenya (Paarlberg, 2001). Additionally, weak IP systems may pose a challenge for local public and private sector investors and developers who have to work around a complex system of IPR laws at the domestic, regional (e.g. provisions set by the African Regional Industrial Property Organization [ARIPO] and the AU Model Law) and international level (e.g. the TRIPS Agreement), with the effect of increasing transaction costs (Chamber *et al*., 2014).

"It must be recognized that biotechnology . . . will not evolve without IPRs, unless there is much more public sector research than seems plausible . . . IP protection is thus a necessary component of a global trade regime in a high technology era" - Barton, 2003 (as cited by Kerle, 2007).

Finally, it should be noted that studies have found that a substantial amount of the economic benefits arising from GM adoption goes towards farmers as opposed to the private companies. For instance, Gouse *et al*. (2004) found that 45-70% of the economic benefits arising from Bt cotton in South Africa went towards the farmers, while 20-52% and 1-3% went to Monsanto and the seed suppliers, respectively.

13.5. Addressing issues associated with Intellectual Property Rights: Capacity building, royalty-free access, increased funding to local public and private crop breeding programs, and protection of Farmers' Rights

East African governments face the challenge of protecting traditional agricultural practices and Farmers' Rights, while still complying with regional and international agreements (Chambers *et al*., 2014). Thus far, little progress has been made in dissecting such issues or developing appropriate IPR policies (Chambers *et al*., 2014). The adoption of a weak IPR system can allow countries to avoid the major issues related to proprietary control, but may as previously mentioned discourage both international and local private and public research, innovation and investments (Fransen *et al.,* 2005). Rather, one should encourage the development of national skill sets capable of handling issues concerning proprietary rights (Chambers *et al*., 2014). Capacity building projects should be initiated to educate and train policymakers, lawyers, scientists and practitioners involved in technology transfer on how to negotiate technology access, manage IP issues and effectively implement IP frameworks (Chambers *et al*., 2014). In 2003, Sida established the Genetic Resources and Intellectual Property Rights (GRP) program in an attempt to meet such needs (Sida, 2003). However, the fact that the initiative was not African-based is believed to have limited its potential impact (Chambers *et al*., 2014).

Consequently, institutions such as AATF have acted as brokers on the behalf of African technology-sharing partners in negotiating royalty-free access to a range of biotechnology advances and applications (ASSAF, 2010). AATF have been relatively successful in negotiating such agreements, including projects such as WEMA, BWX-resistant bananas, VIRCA and NEWEST Rice.

Additionally, East African governments have other tools at their disposal for protecting indigenous and cultural norms, while still facilitating technological advancement – including patent pools, humanitarian licenses, vouchers for support of research competitions, governmental-bought licenses, and so forth (Chambers *et al*., 2013). Additionally, it is important to reduce the reliance on multinationals by increasing funding to public and local private sector crop breeding programs (see Chapter 20 for more information). By doing so, East African governments could become more active in the global debate on the development and ownership of emerging technologies.

Finally, the protection of Farmers' Rights as a way of safeguarding farmer autonomy and in recognition of their contributions to the East African society is pivotal – irrespective of whether or not biotech crops are involved (Borowiak, 2004). Hitherto, it has been challenging to enact Farmers' Rights, which may reflect a lack of practicality (Borowiak, 2004). Thus, efforts should be made to correct short-comings of existing regimes, and analytical studies can be used to identify current barriers to Farmers' Rights. African governments should strive to fulfil the obligations set by the ITGRFA and/or AU Model Law, as well as increasing the awareness on Farmers' Rights among all stakeholders, including the general masses. Furthermore, East African countries should take active part in international policy and decision-making concerning Farmers' Rights and IPRs frameworks, which up until now has displayed a tendency to mostly be in line with a Western notion of ownership tilted towards individual monopoly rights (Kameri-Mbote, 2003; Naluwairo, 2006).

Chapter 14. Gender Equality

The rigid gender-based division of labour within the agricultural sector in many East African countries can both affect and be affected by the introduction of GM crops. For instance, the fact that women are often considered the main agriculturalists, while the men are the primary decision-makers, could limit the uptake of novel technology (Ezezika *et al*., 2012). Furthermore, the introduction of biotech crops could potentially exacerbate gender inequality – if GM crops were to include "male" crops only (Chapter 2, section 2.4) or eliminate a task performed by women, this could further marginalise the female farmer and increase female unemployment. For instance, in the Philippines, the introduction of HT maize might reduce or even eliminate the need for weeding, which is considered a female task (Daño, 2007). Encouragingly, the adoption of Bt cotton in India was found to increase the return to labour, particularly so for hired female workers (Arjunan & Qaim, 2010).

Still, to counteract any potential negative impacts on gender equality, it is essential to inspire women to participate in the primary decision-making and take the role as key players in the GM crop industry. Thus, civil and women rights organisations and (female) farmers coalitions need to encourage governments to implement measures that provide equal access to land, inputs, markets, credit and information by women (Doss, 1999).

Chapter 15. Consumer Choice: To Label or not to Label?

The debate on consumer choice often revolves around labelling of GM food products– a topic which has started to gain more ground in East Africa as the prospect of commercialised events is becoming more evident (e.g. Fig. 15.1). The Kenya Gazette Supplement No. 48 – referred to as the Biosafety Labelling Regulations – introduced mandatory labelling in cases where the product contained >1% GMO content (Republic of Kenya, 2012). Failure to meet the labelling requirements results in a fine of up to 20 million Kenyan shillings (approximately US$190 000) and/or prison for up to ten years (Republic of Kenya, 2012). According to the Ethiopian and Tanzanian regulations, biotech foods must be labelled, but there is no indicated threshold value as of yet (Federal Democratic Republic of Ethiopia, 2009; United Republic of Tanzania, 2009; Tefera, 2015a, b). A similar situation is present in Uganda, but the government has expressed intensions of introducing a labelling policy in the near future (Gruère & Rao, 2007; Chambers *et al*., 2014).

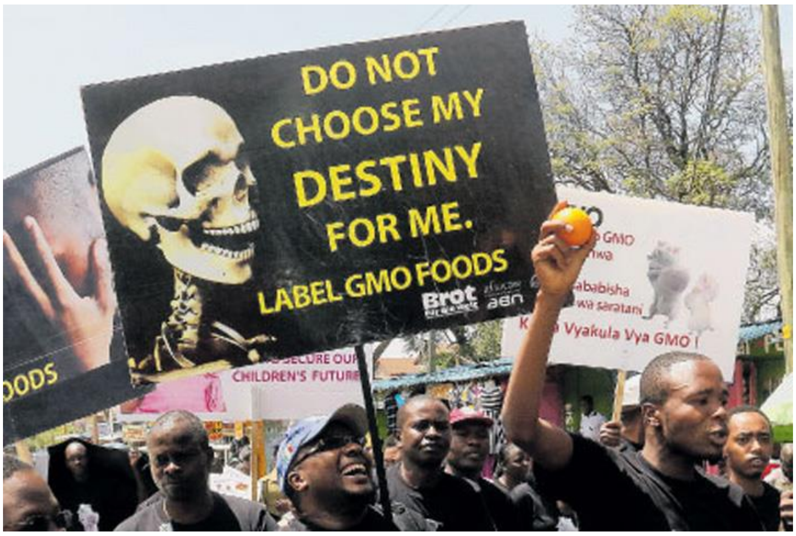


Figure 15.1. Kenyan organic farmers protesting in favour of labelling of genetically modified (GM) food on the World Food Day in 2015. Photo by: Suleiman Mbatiah. From: Andae, 2016d.

Balancing the risks and benefits of labelling of GMO products. Opinions on labelling remain divided – some refer to it as a "consumer rights milestone" (Were, 2012), and stress the importance of labelling as a way of protecting against counterfeiting (a concern expressed by several Kenyan farmers during the field survey), complying with biosafety regulations and tracing the source in case of e.g. negative health effects (Ezezika *et al*., 2012). Others call labelling prohibitive and argue that it may inhibit free and fair trade of GM foods, and could ultimately exacerbate food shortage by incurring additional costs on both consumer and producers (Gichana, 2012).

According to Oh & Ezezika (2014), five main points should be considered when balancing the risks and benefits of GM labelling (note that the list has been somewhat adapted):

(i) The right to know and freedom to choose. Labelling is important in terms of respecting consumer choice and individual concerns related to health, ethics and religion, and may further enhance consumer education and awareness (Lappe, 2002). On the other hand, the "right to know" may stem from a place of fear and uncertainty about, for instance, unjustifiable health and environmental concerns (Mantell, 2002; Persley, 2003; FAO, 2004a). Thus, it is argued that biotech companies and producers will not be acting unethically if they were not to label their products (MacDonald & Whellams, 2007).

Additionally, whether or not consumers will actually pay attention to labels is another consideration. For instance, a study in South Africa found that most consumers were not aware that they were consuming GM foods, despite the country's mandatory labelling law (Botha & Viljoen, 2009).

(ii) Costs and capability. Labelling may impact on every stage of the food production chain and could impose additional costs to farmers, consumers, traders, manufacturers and governments (Oh & Ezezika, 2014). For instance, USDA argues that the Government of Ethiopia does not have the sufficient capacity to enforce labelling requirements (Tefera, 2015a). Consequently, some argue that strict labelling could constrain domestic and international trade (Gruère & Rosegrant, 2008; Kimani & Gruère, 2010), give rise to consumer reluctance and discourage stakeholders (Bett *et al*., 2010); all of which may have particularly devastating effects in developing countries.

(iii) Stigmatisation. The agri-food industry is particularly concerned that labels might stigmatise products that do not deserve such treatment (e.g. through so-called "negative labelling" whereby the product has a label stating that it does *not* contain GMO content). Indeed, even though labels have little or no relation to the safety of the food product (except in the case of allergies, expiry dates, and such), consumers might assume that the product is inherently worse in terms of health and environmental effects. Consequently, labels may be more misleading than informative. A study found that consumers do indeed perceive GM labels as a signal of something negative (Tegene *et al*., 2003), and Bett *et al*. (2010) found that Kenyan gatekeepers would prefer not to label GM products due to the possibility of negative consumer reactions (as well as additional costs).

(iv) Feasibility. How feasible is it to label products sold in bulk or unpackaged, or commodities sold at informal markets (e.g. open-air and roadside markets)? According to the Kenyan regulations, in cases where the products are not pre-packed, the words "genetically modified organisms" or "genetically modified (name of organism)" should appear on, or in connection with, a display of the product (Republic of Kenya, 2012). However, the law also states that regulations should not apply to "food intended for consumption prepared and sold from food premises and vendors", which could include informal markets. If this is the case, then most of the Kenyan consumers would not have access to GM labels and would be left without a consumer choice.

(v) Impact on food security and innovation. If GM labelling was to increase food prices, as well as discourage investors, PPPs and local R&D of biotech crops, then it might have negative effects on food security, poverty alleviation and innovation.

Labelling is further discussed as part of the social science study in Chapter 24.

Part II. Economic Considerations

Chapter 16. Distribution of Benefits and Economic Equality

One of the most essential prerequisites for the widespread adoption of any agricultural technology is its profitability to farmers (Qaim & de Janvry, 2003). As seen in the discussion of IPRs (Chapter 13), a monopolistic market structure whereby a few multinationals exhibit proprietary control may result in extra cost of seeds. For instance, in India, private seed companies have imposed royalty fees up to 67% higher than the retail price of Bt cotton seeds, and farmers have had to pay a "technical fee" of US$50-65 extra per acre when using biotech seeds from Monsanto (Campbell, 1998; Manjunatha *et al*., 2015). Consequently, some fear that biotech crops will work to decrease farmers' profits, restrict access to the farmer elite and ultimately impact on the overall wealth distribution and socio-economic equitability (Qaim & de Janvry, 2003; Lalitha, 2004; Shi *et al*., 2009). Such concerns became evident during the perception studies, whereby some farmers expressed worries about the potentially high price of GM seeds.

16.1. Results from studies on the effect of biotech crop adoption on famers' profit and socio-economic equitability

Results from other developing countries indicate that both elite and resource-poor farmers benefit from the adoption of GM crops (ISAAA, 2016a). In India, the introduction of Bt cotton was found to increase household income by US$43-64 per acre for poor and vulnerable farmers (when compared to conventional cotton), which contributed to poverty alleviation and rural development (Arjunan & Qaim, 2010). In the Philippines, the adoption of Bt maize resulted in a profit gain of US$180 and socio-economic studies have indicated a positive impact on small and resource-poor farmers (Yorobe & Smale, 2012; MASIPAG, 2013). Another study found that small-scale farmers (<1 hectare) in China received more than double the net income of larger-scale farmers (>1 hectare) (Traxler, 2004).

In Burkina Faso, Bt cotton has resulted in an average increase in yield by 18.2% and increased incomes by $61.88 more per ha compared to conventional cotton (Vitale *et al*., 2010). Between 2008 and 2013, the overall economic gain on a national level was US$137 million, and Bt cotton has been estimated to continue generating up to US$70 million per year (ISAAA, 2015a; James, 2015). Additionally, a recent study found that Bt cotton had decreased the use of pesticides by 2/3 and reduced labour requirements (both of which helped offset the higher cost of the GM seeds), and that the achieved benefits were not dependent on farm size (Vitale *et al.*, 2016).

That being said, substantial benefits are not always realised – the net benefit received by Argentinian Bt-adopting farmers was found to be relatively small due to the higher-priced GM seeds (i.e. up to four times that of conventional ones), which offset the gain from reduced application of insecticide and increased yields (Qaim & de Janvry, 2003). Still, a more recent report found that biotech crops had generated an estimated US$ 127 million on the national level from 1996 to 2016, whereby 66% of the benefits had gone towards farmers, 26% had gone to the government, and 8% went to the providers of the technology (which is consistent Gouse *et al*. (2004) whereby farmers received most of the economic returns) (Trigo, 2016).

Contrastingly, some studies from India indicate that conventional cotton may result in higher yields and profit than Bt cotton (Sahai & Rehman, 2004; Quyum & Sakkhari, 2005). However, Sahai & Rehman (2004) & Fransen *et al*. (2005) propose that such findings may reflect planting of illegal and uncertified Bt seeds, which severely challenges the ability of studies to draw conclusions about the performance and economic impacts of GM crops (in terms of both negative and positive results).

16.2. Indications from ex ante economic cost-benefit analyses

An economic *ex ante* cost-benefit analysis can help assess potential impacts of GM crop adoption on famer income, overall profitability, wealth distribution and socio-economics (though such analyses are characterised by certain limitations; see Chapter 23, section 23.3). During analysis, the potential costs (e.g. the cost of seeds, inputs/chemicals, production, and hidden costs such as environmental and health impacts) are weighed against the potential benefit (e.g. the net income). Using this approach, Minde & Mazvimavi (2007) estimated a (conservative) net increase in farm income of up to US$58 million and US$9 million per COMESA country for GM maize and cotton, respectively.

In the case of BXW-resistant GM bananas, Ainembabazi *et al.* (2015) found that the overall input cost would increase by 20-50% when land areas used for banana production was increased by 10-50% (the cost was due to the need of acquiring planting material and establishing new plantations). However, this would attribute to a 25-70% increase in yield, as well as labour cost savings, which would result in a surplus to consumers and producers alike. Additionally, to get an idea of the economic benefit at the national level, parameters such as the total area of cultivation, the production of bananas, research costs, cost of extension services, and price elasticity of demand and supply, were factored in. Over a 25-year period, whereby a 10% discount rate was included, the net benefits ranged from US$20–953 million in target countries (i.e. Burundi, Democratic Republic of Congo, Kenya, Uganda, Tanzania and Rwanda). Thus, it was concluded that investing in the development of transgenic BXW-resistant bananas was of high importance both economically and for food security reasons. However, the authors raised the issue that some farmers might not afford the transgenic planting material, especially those who had already suffered significant losses due to BXW, which could slow down adoption.

16.3. Mitigation measures: Royalty-free access, subsidies, access to credit, seed price & fee intervention, and increased competition

In cases where biotech seeds and trait technology are given royalty-free, one could imagine that the impact on the economic equitability would be limited. In the case in which they are not, governments can implement certain measures in an attempt to minimise the potential socio-economic impacts. For instance, subsidies can be given to resource-poor farmers to facilitate access to credit and technology. However, such measures can be severely challenged by the low equitability that characterises the agricultural sector in many East African countries (e.g. Ethiopia), whereby larger-scale and state-owned farms receive most of the subsidies and have better access to markets (Paarlberg, 2010a; Sánchez, 2010; Azadi *et al*., 2013). Consequently, the elite farmers are often given superior control over the tool of production and a far better starting point than smallholder farmers (Azadi *et al*., 2011). Thus, if subsidies were given to wealthier farms, it could initiate a positive feedback loop whereby the economic surplus gained from growing biotech crops would allow further investment in modern technology, which yet again would provide higher income and more investment opportunities – all of which would work to further exacerbate socio-economic inequality (though some propose that such and similar scenarios could have potential trickle-down effects, see Box 16.1).

Box 16.1. Trickle-down effects. In the case whereby access to, and benefits of, biotech seeds would mainly go towards wealthier farmers, one could picture a scenario whereby the overall profit gain could have "trickle down" effects by, for instance, providing higher investment in the agricultural sector and creation of job opportunities. Some studies have shown that GM-adopting farmers (rich and poor) pass on a significant proportion of the benefits to society (Virgin *et al*., 2007). For instance, in South Africa, Bt cotton-adopting farmers passed on 2/3 of the total benefits (Pray & Naseem, 2003; as cited by Virgin *et al*., 2007). That being said, potential "trickle-down" effects will depend on, amongst others, the government's tendency to reinvest economic surplus in sectors that benefit the rural poor – a tendency which may be limited in some East African countries.

Another mitigation measure, which has gained much traction in countries such as India, is seed price intervention, whereby the state authorities set an official maximum retail price or royalty/trait fee that is lower than the one established by the seed companies (Basu & Qaim, 2007). However, opinions of its effectiveness remain divided – Qaim & de Janvry (2003) argue that price intervention enhance accessibility to farmers and the profitability to companies, while other studies indicate limited impact on dissemination and adoption, while discouraging innovation by corporations (Sadashivappa & Qaim, 2009; Arora & Bansal, 2011). In some cases, governmental price control may be perceived by farmers as a way of saying that they only have the right to cheap technologies, which might lead to farmer reluctance (Sadashivappa & Qaim, 2009). Additionally, private seed companies argue that market forces – e.g. demand, supply and farmer preference – should be the main determinants of the price of seeds (Manjunatha *et al*., 2015). Yet, such market forces may not be particularly prominent in a monopolistic market structure, which has led many stakeholders to be in favour of regulating sale price and trait fees (Manjunatha *et al*., 2015). Still, it should be noted that farmers will always have the option of choosing lower-priced conventional seeds if the price of GM planting materials is considered too high, which restricts this monopoly (Basu & Qaim, 2007). Thus, as suggested by Dr. Oduor, a perhaps better solution would be to promote competition by allowing more public and local private actors onto market. However, this would require governments to alter the current policies and provide incentives for such competition to take place (see Chapter 20).

16.4. Potential socio-economic differences between farmers adopting different farming systems

A final point to consider is how the adoption of biotech crops will affect the socio-economic equitability and relationship between farmers that choose to adopt biotech crops and those that carry out conventional or organic farming. Several studies indicate that GMO-adopting farmers can enjoy substantially higher profit than for those planting conventional crops (e.g. Bennett *et al*., 2004; Vitale *et al*., 2010), while GMO contamination and comingling may hamper future breeding efforts and lower market value of conventional and organic produce (Chapter 19, Box 19.1). Such concerns stress the importance of promoting biotech crops as a complementary tool – transgenic farming is not in direct competition with either conventional or organic agriculture (presupposing that measures to limit gene flow and introgression are implemented; Chapter 5, section 5.8). Instead, the various methods of farming should supplement each other by providing commodities to satisfy a range of different markets and consumer preferences, both locally, regionally and internationally. Thus, as long as all farmers are given equal access to alternative forms of technology and inputs – thus guaranteeing freedom of choice – such concerns should not limit the dissemination and uptake of approved technologies.

16.5. Concluding remarks

Results from other developing countries indicate that poor and small-scale farmers can be among the major beneficiaries of GM crop adoption. Indeed, both Dr. Degefu and Dr. Oduor believed that biotech crops could bring about positive changes in term of narrowing the socio-economic gap. Dr. Degefu said: "I believe GM technology would increase farmers' profit and capital investment in the agricultural system, which would work to gradually narrow the socio-economic gap in the long-term. This is of particular importance in a country [Ethiopia] where 85% of the population is engaged in agriculture".

Thus, the main barrier appears to be the initial access to the transgenic planting material; a barrier which may not be too steep in cases where seeds are given away royalty-free, farmers are given access to affordable credit, and/or seed price intervention is implemented. However, such measures require governments to establish the necessary policies to provide equal access to technology and inputs, especially to the rural poor. Furthermore, in order to lower the cost of GM seeds, governments should provide incentives for public and local private actors to partake in R&D and commercialisation of biotech crop varieties as a way of encouraging competition, which may help drive down the price of biotech seeds and planting material.

Chapter 17. Rural Employment

The introduction of HT and IR crops at the beginning of the 1990s relieved many farmers of the tedious and costly labour of weeding, tilling and de-budding, or the cost of hiring a workforce to do so (Elliott & Madan, 2016). In South Africa, the adoption of GM maize reduced hand weeding by 100 hours per season, which equalled to a reduction of labouring requirements by 50% (Gouse, 2012). However, how will the introduction of biotech crops affect countries where agricultural labour constitutes the largest section of the labour force, and the rural population makes up the majority of society (i.e. 74% in Kenya, 68% in Tanzania, 81% in Ethiopia, and 84% in Uganda; World Bank, s.a.-b)?

The concern is that the introduction of crops such as Bt cotton and HT varieties will leave poor and rural agricultural workers without jobs, which could be particularly devastating in countries with low levels of mechanisation and/or a high average working-age population (i.e. aged 15-64) (Brush, 2001; de Janvry and Sadoulet, 2001; Nuffield Council on Bioethics, 2003; Daño, 2007). Concurrently, wealthy farmers with larger land holdings that would normally hire rural labour, would save on not having to pay legal wages and sustain agricultural labour standards, with the potential consequence of exacerbating socio-economic inequality (de Janvry and Sadoulet, 2001; Daño, 2007).

However, such considerations have to be evaluated against the backdrop of the East African farming system, whereby the majority of farms are smallholder and family-run. Consequently, according to Dr. Oduor, most farmers are able to control weeds by traditional measures. Thus, promoting the adoption of higher-priced HT varieties, in addition to the accompanying herbicides, would be unfound. Such an argument may be all well and good in the case of the currently available HT crops. However, GM crops such as those conferring other types of pest resistance might also relieve agricultural labour requirements. Still, this is not necessarily a problem in cases where labour supply is not readily available (e.g. in part of Africa where diseases such as HIV/AIDS has reduced the working-age population; Nuffield Council on Bioethics, 2003) or for family-driven farms whereby less labour requirements can leave more time for other activities, including tending to other crops (which might contribute to more diverse diets), spending time with the family, or go towards education. Indeed, though not considered among the most pressing constraints, 79% of farmers considered "spending too much time in the field (i.e. insufficient time for other activities)" as "challenging" or "very challenging" to their farming life (Chapter 2, Table 2.2).

Furthermore, in some cases, conventional methods of disease management may not be implemented if they are considered too costly, time-consuming, have negative impacts on the quality of produce, and/or are insufficient to control disease (e.g. in the case of BXW). In such cases, the introduction of pest-resistant crops would pose small or negligible threats to rural employment. Finally, it is not always a given that the adoption of GM crops will lead to reduced management and labour inputs. For instance, Bt-adopting farmers in India experienced an increase in workload in terms of maintenance and harvest, which to a large part was due to higher yields (Qaim *et al*., 2006).

Concluding remarks. It might be necessary to evaluate the impact of biotech crops on rural labour on a case-by-case basis, whereby the potential demerits (e.g. reduced labour requirements and as a result unemployment and increased poverty) are balanced against the potential benefits (e.g. reduced incidences of plant disease, more time for other activities, positive health and environmental impacts due to reduced exposure to harmful pesticides, etc.). Still, conventional measures should be encouraged; if farmers buy GM seeds thinking it will provide them with a silver bullet to all of their problems – e.g. resistance to pests, resilience to drought and improved storage capacity – *without* the need of sustained agricultural labour, then the implementation of biotech crops could backfire. Indeed, some of the farmers surveyed were of the impression that a single transgenic crop variety could exhibit a combination of all desirable traits, and that the crop could be sustained without the need of much labour input. Though stacking of traits allow some form of multi-targeted varieties (within certain limits), it is essential to communicate to farmers that “one GM fits all” is not plausible and that GAP and agricultural labour should be sustained.

Chapter 18. Competition

Adoption of biotech crops may give rise to novel or exacerbate existing competition (Fransen *et al*., 2005), and thus has the ability to change the relationship between nations, and perhaps even more so between developed and developing countries (Palm & Hansson, 2005).

Countries may feel pressured into adopting GM crops in fear of suffering a competitive disadvantage by not doing so (Fransen *et al*., 2005). For instance, as Tanzania and Ethiopia appear to open up for commercialisation, and Uganda is becoming an increasingly attractive destination for foreign biotechnology investors, one could image that the Kenyan government might feel a need to step up efforts to regain its leadership role (e.g. by lifting the ban on GM imports). Furthermore, part of the explanation for the apparent political attitude change and regulatory amendments in Ethiopia and Tanzania could be due to fear of losing out on the regional and international market. For example, the adoption of Bt cotton in Ethiopia could help revive the cotton sector, which will enhance the country's competitive ability against countries such as Burkina Faso. However, competition is one of the main determinants of the profitability of a crop variety (Fransen *et al.,* 2005); thus, if an increasing number of countries start to adopt Bt cotton (or other types of GM crops), thus leading to a global surplus, the market value could decrease which would limit the economic benefits.

An example of novel competition is the adoption of biotech crops engineered to grow in suboptimal climates and soils, with increased tolerance to abiotic stressors, and/or enhanced photosynthetic or nitrogen-use efficiency. Such crops can be cultivated in climatic zones where they previously were unable to grow (e.g. a crop traditionally cultivated in tropical climates that is engineered to grow in temperate zones and vice versa) (Fransen *et al*., 2005). Another example includes a canola engineered to have a high lauric acid content, which is normally a characteristic of coconut oil and makes it highly valuable, and as a consequence could reduce the market value and hamper production of coconut oil (Stabinsky, 2000; Sahai, 2003).

Chapter 19. Market and Trade

19.1. Introduction

Trade relationships can influence the economic prospect of GMO adoption in a country (Fransen *et al*., 2005). Consequently, as touched upon in Chapter 8, many developing countries consider international trade relationship before adopting transgenic crops, and may adjust their trade patterns in response to altered consumer preferences in major export countries (Nielsen *et al*., 2001; Paarlberg, 2006; Makinde *et al*., 2009; Gruère & Sengupta, 2009). For instance, the low traceability and labelling requirements set by the EU (Chapter 8, section 8.1), as well as GM-free private standards put in place by many European food companies, supermarkets, and other traders and producers, are believed to constrain the uptake of biotech crops in many developing countries, even in the case where such crops are not used as export goods (Gruère & Sengupta, 2009; Stewart, 2009). For example, one of the reasons for discontinuing field trials of GM tobacco in Tanzania was due to fear of loss of tobacco exports (Gruère & Sengupta, 2009). Additionally, precautionary regulatory frameworks, ban on the importation of GM commodities and R&D, and rejection of GM food aid (e.g. by Zambia; Chapter 8, section 8.3) have all been justified due to concerns about damaged trade relationships (Paarlberg *et al*., 2006; Paarlberg, 2008; Komen & Wafula, 2014; Waithaka *et al*., 2015).

However, biotech crop commodities are widely accepted in international trade and have been so for the last 20 years (Komen & Wafula, 2014). In 2005, it was estimated that >80% and ~94% of internationally traded maize and soybean was transgenic, respectively (Gruère, 2010). Furthermore, GM crop adoption in countries such as South Africa, whereby ~80% of maize is transgenic, has not constrained the country's export market to Europe (Komen & Wafula, 2014). In fact, the export of fruits and vegetables to countries such as Germany and the UK has steadily increased (according to data available from United Nation's Comtrade Database). In Burkina Faso, the adoption of Bt cotton has led to a substantial increase in exports in recent years (Komen & Wafula, 2014). Then again, when illegally grown transgenic papayas were found in Thailand, many European companies decided to stop importing canned fruit due to fear of GMO contamination (Box 19.1) (Sukin & Sirisunthorn, 2004). Thus, what is the true magnitude of such perceived trade risks for East African countries?

"We have had a huge discussion on GMOs in the EU and have made it crystal clear to farmers in South Africa and here in Kenya that we are not in favour of GMOs. Farmers who grow GM crops will have difficulty exporting their produce to the EU" – Statement by the Head of the European Union delegation in Kenya in 2014 (as cited by Karembu, 2017). The statement was later withdrawn as it was recognised as being inaccurate by the office of the head of delegation (as cited by Karembu, 2017).

19.2. Major import countries and commodities for East African countries

In most cases, the major market destinations for the study countries in question include the African continent and intraregional countries, the United States and Asian countries (Table 19.1). Additionally, European nations such as the Netherlands, the United Kingdom and Switzerland represent major export countries for Kenya and Ethiopia (Table 19.1). Elliott & Madan (2016) further found that the fastest growing market destination for Sub-Saharan exports were China and India, as well as other countries in Southeast Asia.

Table 19.1. Magnitude of exports and imports in billion US$, major export partners, and major agricultural and plant export products of Kenya, Uganda, Tanzania and Ethiopia (in 2015).

Country	Export	Import	Major export partners	Major agricultural and plant export products (% of total export)
Kenya	5.25	17.6	United States (11%), Uganda (10%), Netherlands (8.2%), United Kingdom (7.5%), Zambia (7.4%), Pakistan (6.5%), Egypt (5.1%), Tanzania (4.4%), Germany (3.2%), Russia (3.2%), Rwanda (2.7%), France (1.9%), Italy (1.8%), China (1.8%), Japan (1.3%)	Tea (22%), Cut Flowers (12%), Coffee (4.3%), legumes (2.9%), other nuts (1.3%), tropical fruits (1.3%), other live plants (1.1%), other vegetables (0.73%)
Uganda	2.31	5.52	Kenya (20%), Rwanda (10%), South Sudan (10%), Democratic Republic of Congo (6.6%), Italy (5.1%), Netherlands (5.1%), Germany (4.0%),United Arab Emirates (3.6%), China (3.4%), Belgium-Luxembourg (3.2%), Sudan (3.1%), Tanzania (2.2%)	Coffee (19%), raw tobacco (5.1%), tea (3.5%), corn (3.4%), cocoa beans (3.3%), other oily seeds (2.6%), other live plants (2.4%), raw sugar (1.9%) cut flowers (1.2%), wheat flours (1.1%), rice (0.96%)
Tanzania	6.63	13.5	India (17%), Kenya (12%), South Africa (11%), China (9.4%), Japan (5.6%), Germany (3.1%), Belgium-Luxembourg (3.0%), Democratic Republic of Congo (3.0%), Comoros (2.8%), United Arab Emirates (2.4%), Switzerland (2.4%), Vietnam (2.1%), Malaysia (1.9%)	Raw tobacco (6.5%), coconuts/brazil nuts/cashews (4.7%), dried legumes (3.7%), other oily seeds (2.6%), coffee (2.6%), dried vegetables (1.4%), tea (0.91%)
Ethiopia	5.44	17.6	Kuwait (12%), Somalia (12%), Netherlands (11%), Switzerland (11%), China (7.3%), Saudi Arabia (6.3%), United States (4.9%), Germany (4.4%), Djibouti (3.9%), United Arab Emirates (2.3%), Sudan (1.9%), Japan (1.7%), United Kingdom (1.4%), France (1.3%), India (1.3%), Italy (1.3%), Egypt (1.1%)	Coffee (17%), cut flowers (11%), other vegetables (10%), other oily seeds (8.7%), dried legumes (4.3%), potatoes (0.74%)
Data from UN Comtrade Database/OEC (s.a.).				

On the commodity level, Tanzania was the largest exporter of maize (excluding seed corns) in 2015 (followed by Uganda, Kenya and Etiopia), whereby intra-regional and intra-continental countries represented the major market destinations (UN Comtrade Database/OEC, s.a.). Between 2006 and 2010, Komen & Wafula (2013) found that nearly half of the total value of East African cotton and cotton product exports went to Asia, followed by the other East African countries (~39%) and Europe (~9%). In 2015, Tanzania represented the largest exporter of raw cotton (followed by Uganda and Kenya), and Asia remains the largest export region (UN Comtrade Database/OEC, s.a.). Uganda was the leading exporter of cassava in 2015, whereby Europe and United States represented the leading importing countries (UN Comtrade Database/OEC, s.a.). Uganda was also the top exporter of bananas in 2015, for which Europe constituted the major market (UN Comtrade Database/OEC, s.a.).

19.3. Estimated export losses due to adoption of genetically modified (GM) crops

Gruère & Sengupta (2009) found that Sub-Saharan Africa was the region in which most perceived trade-related risks associated with biotech crops were largely unfound. The reasoning was that most agricultural export commodities included crops that were not grown for the commercial GM market, including coffee, tea, bananas, cocoa, ground nuts, and other fruits and vegetables. The finding is supported by several studies which have found that the level of trade risks is small or even negligible (Anderson & Jackson, 2005; Paarlberg, 2006; Minde & Mazvimavi, 2007; Gruère & Sengupta, 2009; Komen & Wafula, 2013). For instance, a report by RABESA found that the economic loss would be minor in the potential scenario in which biotech crops were adopted and subsequently rejected by all European importers (Paarlberg *et al*., 2006).

Furthermore, for GM crop varieties that are already considered global trade goods (e.g. maize and cotton), and for which most events are approved for planting or importation to the EU, the trade risk would be small (Paarlberg *et al*., 2006; Komen & Wafula, 2013). Besides, as already touched upon, the value and volume of maize and cotton exports to the EU is relatively small, while the major export partners are regional or located in the Middle East and Asia. However, some of the above-mentioned commodities are currently in the East African biotechnology pipeline (Chapter 4), including bananas and cassava, for which Europe represent a major market destination. Yet, some may argue that such transgenic varieties will first-and-foremost be aimed towards household subsistence farming and local consumption, thus might not reach the international market in the foreseeable future. Still, local adoption may have implications on comingling and GMO contamination, which can have further implications for international trade (Box 19.1).

Box 19.1. Organic farming, GMO contamination and potential segregation measures. The interest for GM-free products and organic produce has increased in the EU (Heinze, 2016), perhaps partly in response to the relatively high level of consumer scepticism towards biotech crops (Chapter 8, section 8.1) (Gaskell *et al*., 2006, 2010). Furthermore, organic agricultural products have become an important part of the economy of many developing countries in recent years, and though the organic farming sector in East Africa is small, it is on the rise (Taylor, 2006).

GMO contamination of organic products has been documented with significant loss of market and trade as a result (Freeman, 2004; Paarlberg, 2008). For instance, when the herbicide resistant LL 601 rice produced by Bayer CropScience was found in US rice exports aimed for the EU, it cost the company an estimated US$800 million (Hobbs *et al*., 2013). In fact, the zero tolerance policy on unapproved transgene traits in the EU has cost international commodity traders over US$1 billion during latter years (Smyth *et al*., 2013). Thus, Kenya has expressed fears of comingling of tea exports to the EU (Gruère & Sengupta, 2009), while the Kenya Organic Agriculture Network (KOAN) argues that the adoption of Bt maize and cotton could negatively impact on organically-produced horticultural products (despite such species being sexually incompatible, which prevents hybridisation and introgression from occurring) (Komen & Wafula, 2013).

GMO contamination can be limited if institutional arrangements are implemented in a way that avoids commingling of conventional and transgenic material and produce as far as possible (Gruère & Sengupta, 2009; Horna *et al*., 2013). However, a study found an estimated 15-50% increase in commodity costs in the US and Canada if such countries were to establish parallel handling systems for GM and conventional products (to meet labelling and traceability requirements set by the EU), which ultimately would increase retail food prices by 9-10% (GMA, 2001). Though one could require the applicant (i.e. the one seeking the permit to produce or import a certain biotech crop or product thereof) to bear some of the costs associated with coexistence measures, segregation and subsequent monitoring (e.g. through an importation fee), it would still require competent human resources and the appropriate equipment in order to be carried out in a satisfactory manner (which might be limited in some developing countries). Furthermore, even if East African countries were able to separate their produce, it could result in price segregation whereby conventional crop products are sold at a higher price (for instance to the EU), while transgenic products are exported to markets that do not require segregation (e.g. the US) or with less capacity to pay (Nielsen *et al*., 2001). Finally, segregation might have environmental costs, for instance if different lines would require separate transportation.

19.4. Compensation fund – a potential mitigation measure?

In a scenario where the estimated economic loss due to hampered trade is significant, mitigation measures which allow East African countries the freedom to adopt GM crops without worrying about the potential negative trade impacts could be implemented. Smyth *et al*. (2013) suggest establishing a "compensation fund" for African countries to access in situations where imports are refused by Europe; any commodities that are rejected due to traceability requirements are likely to have a secondary market, though this may come at a lower price or higher access cost. In such cases, African nations could apply for compensation for the financial loss of the exported shipment. The authors propose that the fund should be established by stakeholders from pro-GMO countries, including the US, Canada and Australia. The establishment of such a fund would require substantial efforts and commitment from all partners involved. Still, such stakeholders would also have the most to gain from widespread adoption of biotech crops (Smyth *et al*., 2013).

19.5. Concluding remarks

As opposed to popular beliefs, Europe makes up a relatively modest portion of the East African agricultural export market (with the exception of a few commodities, such as banana and cassava), while destinations located intraregional and intracontinental, in the Middle East and in Asia are comparably bigger and in some cases more pro-GMO. Consequently, the notion that the adoption of GM crops would result in a wholesale rejection of agricultural commodities appears to be a misconception, and studies have shown that the potential economic cost due to loss of trade to Europe is small or even negligible.

Instead, the impact of GM crop adoption on intraregional and intracontinental trade should be of primary consideration (Minde & Mazvimavi, 2007; Komen & Wafula, 2013). Such evaluations might necessitate a case-by-case assessment of the potential trade impacts of the commercialised event (i.e. what crop, which trait, what import country, etc.). For instance, South Africa's major export partners of potatoes are Mozambique and Zimbabwe, in which a cautious approach to GM crops has been adopted (Komen & Wafula, 2014). Consequently, the commercialisation of transgenic insect-resistant potatoes was put on hold until the market behaviours and attitudes towards biotech crops changed (Komen & Wafula, 2014).

Additionally, East African governments have to consider the potential negative trade impacts of not adopting GMOs. Indeed, as the global biotech market and trade increases, the failure of East African countries to embrace novel technologies could hamper their ability to compete on the regional, continental and international market. In this respect, the international community should open up trade barriers in order to facilitate successful adoption of novel agri-technologies. Additionally, regional harmonisation of biosafety and biotechnology laws and regulation could work to mitigate potential negative trade and market effects of GMOs among neighbouring countries (Waithaka *et al*., 2015).

As a final note, issues related to GMOs and trade raise some interesting, and at times ethical, questions. For instance, is it justifiable to adopt GMOs if comingling may hamper farmers' and consumers' rights to GMO-free seeds and food products? Also, why does the prospect of GM products or GMO contamination originating from African countries appear "worse" than for the equivalent originating from countries such as Brazil? Is the European market not already "in danger" of GMO contamination and comingling from its 40 million tonnes yearly imports of GM products? And who is really to "blame" for spreading seemingly unjustifiable concerns about potential trade implications?

Chapter 20. Public and Private Sector Research and Investment: Can East African Countries Afford Biotech Crops?

20.1. Introduction

The price tag on a biotech crop project can be substantial – for instance, between 2008 and 2012, the estimated cost of the discovery, development and authorisation of a new GM trait was US$136 million (McDougall, 2011). However, the price tag can be considerably less – at discounted prices, the cost of developing Bt maize in the Philippines was estimated to be US$2.6 million (in 2004) (Manalo & Ramon, 2007), while the IRMA project and the development of transgenic sweet potatoes came at US$6 and US$2 million, respectively (UNEP, 2007). Still, in comparison, projects involving tissue culture and marker technology has been found to cost around US$300 000 (UNEP, 2007).

Furthermore, the successful widespread adoption of biotech crops have other costs, including (i) developing and sustaining an effective regulatory framework (the cost of regulatory requirements associated with GM products is recognised a major demerit when compared to traditionally-bred varieties) (Nap *et al.,* 2003; Zepeda *et al*., 2003; Cohen, 2005; Manalo & Ramon, 2007); (ii) dissemination of the technology to farmers, e.g. via extension services; and (iii) awareness campaigns and communication measures to ensure compliance with legal frameworks and GAP, which can be particularly challenging and costly in countries with a lack of adequate infrastructure and road connectivity (UNDP, 2012). Furthermore, funding allocated to human, scientific, technical, and infrastructural capacity building might be necessary. Consequently, in a region where most countries are defined as "low income" and governments are underinvesting in science and agriculture, the question thus arise: Are East African countries able to afford, develop and sustain transgenic technology and biotech crops?

20.2. Public and local private sector engagement

Research conducted by public institutions is pivotal for the development of pro-poor and situation-specific biotech crops (Cohen, 2005; Virgin *et al*., 2007). Currently, certain East African national agricultural research institutes, universities and science commissions receive governmental funding (e.g. KALRO in Kenya, NARO in Uganda, Mikocheni Agricultural Research Institute in Tanzania, and the National Agricultural Biotechnology Research Centre in Ethiopia). Still, inadequate monetary resources and weak public breeding systems are considered major obstacles for harnessing the benefit of biotechnology and addressing the challenges faced by smallholder farmers (Cohen, 2005; Fransen *et al*., 2005; Virgin *et al*., 2007; Ecuru & Naluyima, 2010; Lopatto, 2015). Furthermore, the contribution from local private companies is limited (though a few private institutions do exist, such as African Harvest in Kenya and Agrogenetic Laboratories Ltd in Uganda), and has been identified as one of the weaknesses of transgenic research in countries such as Uganda (Ecuru & Naluyima, 2010; James, 2015).

Consequently, many national research institutions and biotechnology projects rely on donor funding (usually from bilateral and multilateral agencies) and/or involvement by private multinational corporations, often as part of public-private partnerships (PPPs) (Odame *et al.*, 2002; Ayele *et al*., 2006; Virgin *et al*., 2007). Examples include the Rockefeller Foundation, the Syngenta Foundation, the Bill and Melinda Gates Foundation, the Howard G. Buffet Foundation and the Monsanto Company.

20.3. Public-private partnerships – a recipe for success?

Public-private partnerships (PPPs) constitute local/foreign and public/private entities which carry out research that neither the public or private sector could have done independently. Partnerships often allow for access to privately-owned technology, resources and funding for public good and public sector research, and mechanisms for dissemination of the technology (Hall, 2006). Consequently, PPPs have been recognised as a necessity for improving agricultural productivity and food security in Sub-Saharan Africa (Hall *et al*., 2001; Ezezika & Oh, 2012).

One example is the IRMA project which was established in Kenya in 2000 and has been deemed a "blueprint" for a successful PPP (though the project has been criticised for focusing on stem borers rather than grain borer, of which the latter is considered a more serious pest of maize in Africa) (Chataway, 2005; Ayele *et al*., 2006; Spielman, 2007). KALRO contributed scientific and institutional capacity, as well as linking the research with an extension system; the International Maize and Wheat Improvement Centre (CIMMYT) provided lines with Bt genes, as well as expertise within genetic engineering and biosafety; while the Syngenta Foundation provided funding and access to private sector training (Chataway, 2005).

However, some argue that the positive effect of PPPs has yet to be realised, owing to factors such as disparate working styles of the partners involved; IPRs frameworks; unsupportive institutional arrangements; short-term private funding or dependence on aid; cultural clashes and lack of trust between stakeholders; being science-led as opposed to user-driven, and lacking clear end user-goals; being weakly linked to innovation within food production; and/or being small and loosely organised (Ayele *et al*., 2006; Hall, 2006; Spielman, 2007; Muraguri, 2010; Ezezika & Oh, 2012; Bailey *et al*., 2014). For instance, representative from a Ugandan NGO that partook in the stakeholder survey believed that funding-driven R&D compromised farmer-based research, and further argued that farmers had come up with novel and traditional methods of reducing and eliminating transmission of diseases such as BXW, but that this was overlooked as it was not popularised by biotech research.

Some of these issues may reflect the fact that the development and application of agricultural biotechnology often have been conducted within a North-South framework and with a top-down approach (i.e. whereby donors look for countries in which they are most likely to succeed) (Ayele *et al.,* 2006; Muraguri, 2010). This might explain why considerably fewer PPPs have been established in Tanzania and Ethiopia hitherto, as these countries have a shorter history of practical experience using the technology; exhibit relatively low scientific, technological and human capacity; have had regulations containing strict articles related to liability and redress; and a lack of legal guarantees that the products may ultimately become commercialised. Thus, it will be interesting to see whether the recent regulatory amendments will increase the number of PPPs established in the two countries.

20.4. Could a bottom-up approach give rise to more successful PPPs?

Thus, a bottom-up approach, whereby the consumers seek solutions to agricultural problems, could be more suited at addressing the developmental goals of the East African nations (Muraguri, 2010), as well as reducing the impression that biotech crop innovations are being imposed by the Western world. Such an approach would require East African governments to develop clear policies on how partnerships should operate in order to focus R&D on situation-specific biotech crops, as well as avoiding a power dispersal biased against the government (Muraguri, 2010). Additionally, efforts to build trust between stakeholders should be encouraged, which according to Ezezika & Oh (2012) can be achieved by improving integrity, delivery, capability, mutuality, transparency and humanitarianism. Consequently, if PPPs are designed with credibility and efficiency in mind, as well as on a case-by-case basis (as pro-poor knowledge and technology can vary significantly), such partnerships may play a pivotal role in the further development of the agricultural and agri-biotech sectors in East Africa (Spielman *et al*., 2007).

20.5. Concluding remarks

East African governments should strive for development and dissemination of niche GM crops within the nation's own agricultural research system and via national extension services, respectively (Paarlberg, 2001). Governments need to keep in mind that the apparent costly investment in biotechnology may quickly be recovered, and that the economic gain may further promote development and growth of other sectors (Azadi *et al*., 2011). Such investments can lead to a positive feedback loop where the end result is increased human knowledge, health, productivity and income, which creates the foundation for future innovations (UNDP, 2012). Though such political commitment may be severely challenged by factors such as corruption, political upheaval, war and conflict, and health issues, recent investment by e.g. the Ethiopian government in agricultural research shows that progress can be achieved with adequate political will.

Furthermore, engaging the local private sector could help drive the debate on GM crops and the development of the agricultural technology sector. Bailey *et al*. (2014) suggest an advanced market commitment approach where public funds are used to underwrite market demand for actors within the private sector, which might give them an incentive to take active part in the whole process – from the early stages of R&D and all the way to commercialisation. In this respect, it is also important to provide private agribusinesses with products that are of commercial interest (in other words, conduct research that is also industry-driven), as suggested by Dr. Oduor. Additionally, governments can support so-called spin-off bioscience-based companies or provide venture capital in order to attract a workforce and scientists interested in starting their own enterprise (Ecuru & Naluyima, 2010). Also, public research institutes and organisations could licence innovations to the private sector (Ecuru & Naluyima, 2010). Finally, high regulatory costs may discourage small local companies and ventures, which underline the need of developing a facilitating and efficient regulatory framework (Meijer & Stewart, 2004).

Chapter 21. Distribution, Accessibility and Infrastructural Short-Comings

Studies have found that the real issue of food insecurity is currently not production, but down to distribution, accessibility and poverty (Persley & Lantin, 2000; Pew Initiative on Food and Biotechnology, 2001b). Furthermore, several authors, professionals and surveyed stakeholders argue that African countries lack the appropriate infrastructure to facilitate widespread GM adoption and to reap the true benefits of the technology, including roads, access to markets, post-harvest storage facilities, extension services, irrigation systems, and research facilities (Cooke & Downie, 2010; Lopatto, 2015). For instance, what is the point of investing in costly GM seeds if farmers cannot bring surplus produce to market or if there is not adequate water to sustain such crops? Furthermore, studies

21.1. Storage opportunities, travel time and road connectivity, and market access

Farmers may become reluctant to grow extra crops and/or adopting new technology when there are inadequate opportunities to store, transport and sell produce before it rots (Lopatto, 2015). A 2005/2006 household survey found that 30% of Ugandan communities lacked access to roads (Uganda Bureau of Statistics, 2014), while more than half of the population in a majority of East African countries have been found to reside more than five hours away from a market centre which, more often than not, are underdeveloped and/or inefficient (Salami *et al*., 2010). For example, a study found that the average Ethiopian farmer has to walk for half a day to reach a local market whereby the price for his or her products can be up to 70% lower than for urban markets (Hanjra *et al*., 2009). In support of this, 71.8% of the surveyed farmers characterised "poor infrastructure for market access (roads, communication)" as a major challenge to their farming life (Chapter 2, Table 2.2), and one of the major characteristics that farmers looked for in a GM variety was marketability, both locally and internationally.

Inadequate road infrastructure and long travel time (e.g. to urban markets) can give rise to high transaction costs for agricultural inputs and outputs, makes farmers highly vulnerable to fluctuations in food prices, and may force farmers to buy seeds at a high price while selling their produce at low (Dorosh *et al*., 2009; UNDP, 2012). Consequently, this leaves little or no capital for investing in improved seeds, irrigation technology, better tools and fertilisers (Hanjra *et al*., 2009). Indeed, travel time to urban areas has been shown to be negatively correlated with adoption of productive/high-input technology in East Africa (Dorosh *et al*., 2009). Consequently, it is important to improve road connectivity and reduce travel time in order to expand the feasible market size and facilitate transfer of technology, as well as a mean of increasing farm education and awareness on GMOs (Dorosh *et al*., 2009). This is particularly important for women who have limited opportunity to travel due to other responsibilities in the home (Lopatto, 2015).

21.2. Irrigation

Most East African farmers rely primarily on rainfed agriculture due to limited access to irrigation-based resources, which promotes agricultural business as a risky investment by governments and people alike; an issue which is exacerbated by unexpected rainfall patterns and drought as a result of climate change (Mwaura & Katunze, 2014; Nicol *et al*., 2015). According to FAO, the percentage of irrigated land is 2.5-2.7% in Kenya (in 2005), 2.2-5.6% in Uganda (in 2012), 2.4-2.9% in Tanzania (in 2009) and 0.6-1.9% for Ethiopia (in 2012) (FAO, s.a.-d). In support of this, 83.4% of stakeholders and 90.5% of the surveyed farmers reported "lack of irrigation systems" as "challenging" or "very challenging" to East African farming systems and partly to blame for low yields (Chapter 2, Table 2.1 and Table 2.2).

That being said, lack of irrigation systems is not an issue restricted to the use of biotech crops, but one that concerns the entire agricultural sector, and is often caused by poor management of water resources and low governmental investment in irrigation. For instance, most parts of Uganda and Ethiopia have sufficient water resources, but these are not efficiently harnessed due to lack of awareness, infrastructure, management and conservation (Hordofa *et al.*, 2008; FAO, 2014c; Mwaura & Katunze, 2014). Furthermore, as seen in Chapter 3 (section 3.2.2), biotech crops could offer a way in which plants can be made more resilient to water stress and drought, as in the example of the WEMA.

21.3. Lack of research and regulatory capacity

The process of bringing a biotech crop variety from the laboratory to field trials, through the various regulatory steps, and finally to market, requires sufficient facilities and human expertise at all levels. Studies have found that stakeholders – particularly so from regulatory institutions in Kenya, Uganda and Tanzania – felt that inadequate training and expertise was a major – if not the main – obstacle for the further development of, and access to, agricultural biotechnology in their own and other developing countries (Pray & Naseem, 2003; Ezezika *et al*., 2012). For instance, in Tanzania, poor communication facilitates, inadequately equipped libraries, outdated laboratory equipment and inefficient transportation have been found to be major bottlenecks for the national agricultural research centres (Virgin *et al*., 2007).

Consequently, development of human resource capacity – be it scientific, technological, organisational or institutional – and well-equipped laboratories and facilities should be of top-most importance in ensuring the safe application and delivery of biotechnology. This accentuates the importance of initiatives such as BIO-EARN, ASARECA, PBS and various CGIAR centres. However, such efforts also requires governments and policymakers to, amongst others, implement appropriate policies and legal frameworks; improve institutional management; increase predictable and transparent budgetary support both directly and on a competitive basis; facilitate private sector engagement; establish capacity building and human resource development projects; provide biosciences and biotechnology-related studies at higher educational levels and encourage students to pursue careers within such fields; strengthen synergies between biotechnology companies and investors both locally and internationally; and establish state-of-the-art testing and certification facilities (Ecuru & Naluyima, 2010). Such efforts require substantial monetary and human resources which can be limited in developing countries. However, Ethiopia is a good example whereby research capacity has long been considered relatively low, but recent investment in biotechnology has led to promising developments in a relatively short amount of time. Furthermore, this is where the international community and regional joint efforts can play an important role in facilitating sharing and exchange of information, human resource and expertise, and facilities.

21.4. Concluding remarks

East African countries have certain infrastructural limitations, whereby the perhaps biggest obstacle to GM adoption is the lack of appropriate scientific, institutional and regulatory capacity. Furthermore, improving infrastructure such as road connectivity can positively impact on the uptake and dissemination of technology. However, instead of using infrastructural short-comings as an argument against agricultural biotechnology, the adoption of GM varieties and new technology could serve as a driving force for improving such limitations. For instance, if the widespread adoption of a certain technology results in a commodity surplus, it may lead to a higher demand for improved road connectivity, storage spaces and markets by various stakeholders. Furthermore, arguments concerning infrastructural limitations are not an issue restricted to the GMO debate, but apply just as much to conventional and organic farming – or indeed most sectors in society.

Chapter 22. Lessons Learned from the Green Revolution: What Can History Teach Us?

The available literature on the impacts of biotechnology on societal factors is rather scarce, perhaps because many socio-economic impacts are dynamic and may become evident over time. Consequently, by taking a small look back in history to the Green Revolution, one might gain some clues as to what to expect from a Green Revolution 2.0, as well as learning some valuable lessons.

What was the Green Revolution and what impacts did it have? The Green Revolution took place from the 1930s until the late 1960s, and included the introduction of high-yielding dwarf varieties of cereals like maize and wheat, increased input of agri-chemicals (e.g. fertilisers and pesticides), and the introduction of improved irrigation systems, mechanisation and various subsidies (e.g. production and market price subsidies, protected markets and guaranteed purchase of output by governments) (FAO, 2004a; Virgin *et al*., 2007; Pingali, 2012). The Green Revolution was most prominent in Latin America, China, Southeast Asia, India and the United Kingdom, and has been praised for saving the lives of millions by alleviating hunger, malnutrition and poverty, as well as having beneficial environmental effects (Conway, 1999; Wu & Butz, 2004; Virgin *et al*., 2007; Pingali, 2012). However, some argue that the positive impact of the Green Revolution has been overestimated – the increased use of pesticides, herbicides and inorganic fertilisers has put burdens on the environment and human health, and several socio-economic effects are claimed to have risen in the aftermath of the revolution (Conway, 1999; Savci, 2012; Kumari *et al*., 2014; Catarino *et al*., 2015).

The impact of the Green Revolution on socio-economic equitability among small and large-scale farming communities show contradictory results – in southern parts of India, after a slight delay in adoption rate by small-scale farmers, there was no systematic difference in the adoption of high-yielding varieties according to farm size (Hazell *et al*., 1991). However, Biasucci (1997) argues that the opposite was true on a national level. In other parts of Asia, studies have found an increase in socio-economic inequality between large and smallholder farmers (Cleaver, 1972; Hanumantha, 1975; Griffin & Ghose, 1979). This could be explained by the fact that the Green Revolution was largely based on intensification of already favourable areas, thus leaving farmers of less favoured and rural parts lagging behind (Fan & Hazell, 2001; Pingali, 2012). Additionally, the increased cost of agricultural inputs is believed to have intensified income inequality and distribution of wealth by making inputs inaccessible to poorer farmers (or alternatively putting them in greater debt) (Conway, 2003).

In some areas, new classes of agricultural workers arose (e.g. merchants that specialised in rice trading and labourers that took on seasonal work in rice farms) which caused a shift in the labour dynamics (Daño, 2007). In some societies, female farmers and female-headed households gained markedly less benefits than their male counterparts due to reduced need for female labour and because the technology transfer was mainly aimed towards male farmers (Conway, 1991; Paris, 1998; Doss, 1999; Pinstrup-Andersen & Cohen, 2001; McIntyre *et al*., 2009).

Concluding remarks. Though the Green Revolution may provide some indications of what one might expect from a second revolution, the two are not directly comparable. For instance, today's agricultural innovations are mainly dominated by the private sector (with stricter IPR frameworks), while the Green Revolution was mostly driven by public institutions (though multinational chemical fertiliser companies were present, for instance in India; Biasucci, 1997), as well as being operated via subsidies and protected markets (Virgin *et al*., 2007).

Still, valuable lesson can be gained from the Green Revolution (for which there are several reviews, e.g. Wu & Butz, 2004). For instance, impacts might vary temporally and spatially –results may differ between and within countries which goes to show that the same technology, or the way it is employed, is not necessarily readily transferable from region-to-region. This underlines the importance of developing niche and situation-specific biotech crops that employ local germplasm for optimal adaptation. Furthermore, both positive and negative socio-economic effects may become apparent with and change over time (e.g. small-scale farmers may catch up on the adoption of technology at a later stage), which necessitates the need of collecting data over time when conducting socio-economic studies.

Finally, and perhaps most importantly, some of the positive and negative impacts of the Green Revolution was a result of governmental policies rather than the technology *per se*. For instance, for the latter, policies that promoted injudicious and overuse of chemical inputs and expansion of cultivated land led to unwanted environmental effects, while those that restricted dissemination of the technology to certain favourable areas or societal groups (e.g. men) gave rise to unwanted socio-economic impacts. For the former, governmental strategies to alleviate poverty, such as social safety net programs, investment in the agricultural sector, rural development and education, and equal access to resources like land and credit, is believed to have enhanced the positive impacts seen in parts of India (Pinstrup-Anderson & Cohen, 2001). Consequently, when introducing a new technology such as biotech crops, it is pivotal to ensure equal access to the technology, especially for marginalised groups and/or areas (e.g. women and rural regions); concentrate efforts on protection of Farmers' Rights (e.g. issues related to inequitable distribution of land and land tenure; poor access to credit and input/output markets; and unequal allocation of subsidies); promote sustainable and good agricultural practices; and support development of other sectors (e.g. health, education and overall infrastructure).

Chapter 23. Including Socio-Economic Considerations in Regulatory Systems Governing Biosafety and Biotechnology

23.1. Considerations and parameters for inclusion of socio-economic factors in regulatory systems governing biosafety and biotechnology

When including socio-economic considerations (SECs) in the regulatory process, some of the considerations needed are, but not limited to:

i) Which socio-economic factors to include in the methodological framework.
ii) The appropriate level and scope of analysis. For instance, whether to include or exclude SECs that arise outside the nation's borders; the time frame in which analysis should operate; whether both living (e.g. plants and seeds) and non-living products (e.g. meal) should be included; if analysis should be concerned with all potential uses of GM products, e.g. in biofuel, for animal feed and/or human food products; if analysis should be limited to SECs that arise from impacts on imports, exports, cultivation, etc.
iii) The reference alternative/null value that the GM crop product should be compared to.
iv) At what stage(s) during the regulatory process SECs should be incorporated (e.g. during deliberate release, post-release monitoring, commercialisation, etc.).
v) How results should be analysed and how they should be weighed in relation to data obtained from biophysical evaluations (e.g. effects on biodiversity, gene flow, non-target organisms, allerginicity/toxicity, etc.).
vi) Which institution(s) that should be responsible for the assessment.
vii) At what level the competent authority will either accept or reject approval of the technology.
viii) Public participation as a way of identifying and resolving socio-economic issues.

Note: List adapted from Fransen *et al*. (2005) and Horna *et al*. (2013).

23.2. Socio-economic considerations in selected international and East African biosafety and biotechnology frameworks and policies

23.2.1. International

Article 26.1 of the Cartagena Protocol provides Member States with the option of including socio-economic impacts as part of the decision-making concerning biosafety, but narrowly defines impacts as those arising from LMOs on biological diversity and conservation, especially with regards to indigenous and local communities (CBD Secretariat, 2000; MacKenzie *et al*., 2003). The Protocol further states that implementation of SECs must be "consistent with international obligations", such as the WTO's provisions for socio-economic considerations associated with trade, which includes the General Agreement on Tariffs and Trade (GATT), the Sanitary and Phytosanitary Measures (SPS), the TRIPs Agreement and the Technical Barriers to Trade (TBT) Agreement (Smyth & Falck-Zepeda, 2014). However, the Protocol makes no reference to SECs under Article 15 concerning risk assessment, thus do not provide clear guidelines on how or when such considerations should be taken into account (MacKenzie *et al*., 2003). Consequently, there are currently on-going efforts and discussiosn among the signatories of the Cartagena Protocol – as well as within the European Union – on how to incorporate socio-economic aspects into the risk assessment for GMOs (COGEM, 2009; UNEP, 2014; European Union, 2015). In this respect, Norway has been one of the pioneer countries, as it was one of the first to include assessment criterias related to ethics, societal utility and sustainable development in their regulatory frameworks (Miljøverndepartementet, 1993).

23.2.2. The AU Model Law

As already touched upon in Chapter 7, the AU Model Law recognises the need of including socio-economic and ethical considerations during risk assessment of GMOs and GM products. The Model Law exhibits a broader scope than the CPB and defines SECs as: "i) Anticipated changes in the existing social and economic patterns; ii) Possible threats to biological diversity, traditional crops or other products and, in particular, farmers' varieties and sustainable agriculture; iii) Impacts likely to be posed by the possibility of substituting traditional crops, products and indigenous technologies (…); iv) Anticipated social and economic costs due to loss of genetic diversity, employment, market opportunities and, in general, means of livelihood of the communities; v) Possible countries and/or communities to be affected in terms of disruptions to their social and economic welfare; vi) Possible effects, which are contrary to the social, cultural, ethical and religious values of communities" (African Union, 2007). Any GMO or GM product found to have "adverse socio-economic impacts" or do not fulfill requirements of "according with the ethical values and concerns of communities and does not undermine local community or indigenous knowledge and technologies" are to be witheld from release.

23.2.3. Socio-economic considerations in East African regulatory systems

In line with the AU Model Law, the regulatory systems of Kenya, Uganda, Tanzania and Ethiopia all state that socio-economic implications shall be taken into consideration during regulatory decision-making, and that approval shall not be given in case of adverse impacts (Government of the Federal Republic of Ethiopia, 2007; Republic of Kenya, 2006, 2009b; Republic of Uganda, 2004, 2008, 2012; United Republic of Tanzania, 2004a, 2004b, 2005, 2009). However, as the Biotechnology and Biosafety Bill has yet to be passed into law, Uganda has strictly speaking not made a final decision on whether or not – and in what way – to include SECs in their framework.

Kenya

The Kenyan Biosafety Act of 2009 states that the authority (NBA) shall take into account "socio-economic considerations arising from the impact of the genetically modified organism on the environment (…)" when evaluating an application (Republic of Kenya, 2009b). The NBA has listed certain SECs that applicants for environmental release must provide information on, including issues related to comingling, farmers' income and trade implications (Appendices 3, Appendix A).

Uganda

The National Biotechnology and Biosafety Bill of Uganda states that one of the functions of the Competent Authority is to "consider necessary measures to avoid adverse effects on (…) socio-economic conditions arising from a GMO" (Republic of Uganda, 2012). The National Biotechnology and Biosafety Policy requires applicants for general release to: "(i) identify any potential positive or negative socio-economic effects of the proposed general release activity in Uganda or within the target population; (ii) identify any possible bio-ethical aspect of the general release activity; (iii) suggest measures to limit any potential negative socio-economic or ethical considerations" (Republic of Uganda, 2012). The Policy further recognise the following statements and actions associated with aspects of socio-economics: "Bioethics and Biosafety" (*"mechanisms will be put in place to develop and apply Biotechnology in accordance with acceptable societal morals"*); "Indigenous Knowledge and Practices" (*"indigenous knowledge will be integrated in the development and application of* *modern Biotechnology"*); "Gender Considerations and Equity" (*"biotechnology is a technology that has a big potential of reducing the burden of manual labour. (…) less frequency of weeding, effectively use water reserves and are more convenient to harvest, (…) will reduce on the time spent by the women and the children (who form the majority) on the farm")* (Republic of Uganda, 2008).

Tanzania
The Tanzanian Biosafety Regulations of 2009 define SECs as set by the AU Model Law (United Republic of Tanzania, 2009). Additionally, the National Biosafety Framework states that "*socio-economic and ethical concerns arise due to companies control of their processes, genes and chemicals. Socio ethical concerns revolve around ethical or dietary implications of vegetarians or certain religious groups and choice of consumers*" (United Republic of Tanzania, 2004b). The biosafety guidelines also raise issues associated with IPRs (including protection of indigenous varieties, traditional knowledge and biodiversity), comingling of products, consumer choice and religious implications (United Republic of Tanzania, 2005; Mtui, 2012).

Ethiopia
In the outline of the draft NBF, it is stated that the EIA shall "address social, socioeconomic, political and cultural conditions". SECs are to be incorporated during risk assessment and should "include a cost-benefit or socio-economic analysis". In the case where there is "imminent and serious danger to (…) socioeconomic conditions or cultural norms of local communities (…)", the authority (EPA) shall withdraw any authorisation and carry out the appropriate mitigation measures (Government of the Federal Republic of Ethiopia, 2007).

The original Ethiopian Biosafety Proclamation contained strict provisions for socio-economic assessment which focused mostly on the potential risks rather than benefits (Abraham, 2013). The Proclamation defined socio-economic impacts as "*direct or indirect adverse effect that results from a transaction on the social or cultural conditions, the livelihood or indigenous knowledge systems or technologies of a local community, including on the economy of the country"*, and further defined risks as *"direct or indirect, short, medium or long-term danger that may befall (…) socio-economic or cultural conditions of local communities or the economic condition of the country from any transaction"* (Federal Democratic Republic of Ethiopia, 2009). Directive No. 2/2009 further elaborated on potential risks, including effects on employment, market and trade, traditional crops and indigenous technologies, and religion and ethics (Government of the Federal Republic of Ethiopia, 2008; Abraham, 2013).

The revised Proclamation expand slightly on the definition of risks, namely *"short, medium or long-term danger that may befall on (…) socio-economic conditions arising from the impact of modified organisms on the conservation and sustainable use of biological diversity, especially with regard to the value of biological diversity, indigenous knowledge systems and local communities*" (Federal Democratic Republic of Ethiopia, 2015). To the best of this authors knowledge, the directives have yet to be approved by the Ministerial Council to be made available to the public (as of May 2017), thus it remains to see whether the new Directives will contain addition information on SECs and how to incorporate these during risk assessment (and whether the provisions will be considered less strict as those set by the original directives).

Concluding remarks

There is a lack of clear guidelines both internationally and in the East African region on how to incorporate SECs into regulatory decision-making. For instance, articles related to SECs in East African regulatory frameworks have several limitations, such as the lack of (i) a clear definition of which SECs to incorporate during assessment (the Tanzanian Biosafety Regulations of 2009 and Ethiopian Proclamation provide the clearest definitions, while the Kenyan NBA has listed a few for the conditional approval for environmental release; Appendices 3, Appendix A); (ii) guidelines for safety assessment, e.g. how and when to include SECs; and (iii) how the data should be analysed (Jaffe, 2006).

23.3. Implementing socio-economic considerations in biosafety decision-making: Challenges and opportunities

By implementing SECs in the safety assessment of GMOs, one can minimise or avoid potentially irreversible social, cultural, ethical and economic costs. However, some argue that socio-economic factors are "too vague", "outside the domain of biosafety" or "uncontrollable" (Daño, 2007). Furthermore, the inclusion of SECs in regulatory decision-making remains controversial due to several ill-defined parameters (e.g. defining the scope, identifying target populations, analysing risk-benefits, how to measure SECs that cannot be directly quantified e.g. in terms of monetary costs, etc.), as well as the various options for design, methodologies and implementation in the regulatory process.

Additionally, there is limited available information on socio-economic impacts of biotech crops, as well as lack of practical experience in including such issues in regulatory decision-making. Furthermore, including provisions on socio-economics does not guarantee compliance with the law, and requires judicial support and strong political will to be implemented effectively (Collier & Moitui, 2009). All such considerations increase the complexity of risk assessment and consequently the time and budgetary requirements, which can be particularly constraining in countries with limited monetary, human and infrastructural resources (Daño, 2007; Chambers, 2013; Horna *et al*., 2013; Chambers *et al*., 2014).Thus, including SECs may become a limiting factor on the number of potentially advantageous biotech crop varieties that make it through the regulatory process, which ultimately may have negative impacts on food security.

Consequently, SECs need to be incorporated in a way that is adaptable (e.g. to different crops and technologies), transparent, predictable, consistent, inclusive (to all relevant stakeholders), robust, scientific, testable, and time and cost effective, while still complying with international agreements and obligations to which countries may be bound (Garforth, 2004; Falck-Zepeda & Zambrano, 2011; RAEIN-Africa, 2012; Chambers *et al*., 2014).

Recommendations

Fransen *et al*. (2005) and Horna *et al*. (2013) have listed a set of practical recommendations for integrating SECs into biosafety decision-making, of which some include:

i) Governments need to define those criteria listed under "inclusion of socioeconomic considerations in the biosafety regulatory system" (Fransen *et al*., 2005), especially with poor, smallholder farmers in mind. This might require a distinction between "real" concerns and those that do not weigh heavily enough to prevent adoption of new technology. In this respect, it might be beneficial to rule out SECs that are not suitably dealt with using policies and regulations that govern biosafety and biotechnology due to conceptual and/or practical reasons. For instance, IPRs or issues associated with consumers may be better addressed by laws related to patenting and consumer rights, respectively (Fransen *et al*., 2005).

ii) In order to facilitate transparency and cost-efficiency, governments should employ independent social scientists to carry out assessments, as well as establishing strict time frames and streamlined procedures (Fransen *et al*., 2005).

iii) One should use scientifically-sound research tools and methods (see below) that are carried out in an objective, analytically sound, multidisciplinary and independently conducted manner, while still considering time and budget constraints (Fransen *et al*., 2005; Horna *et al*., 2013).

iv) One should allow for inherent uncertainties that arise during assessment by including a range of values for the chosen parameters being evaluated (e.g. yield, technology efficiency and price) (Horna *et al*., 2013).

v) The scientific community should employ mechanisms for assessing socio-economic issues that arise during the research process, and include socio-economic assessments in the work plan, time frame and the budget of a project (Fransen *et al*., 2005).

vi) The biotechnology industry should aim to identify potential socio-economic concerns as early on in the process of development as possible (Fransen *et al*., 2005).

vii) The technical ability of NGOs and civic society groups should be enhanced in order to improve the ability of identifying and analysing socio-economic factors in a peer-reviewed manner, and as a way of engaging scientists, companies and government agencies (Fransen *et al*., 2005).

viii) Public awareness and participation should be promoted and made part of the legislation and institutional arrangements (Fransen *et al*., 2005).

Tools and methodologies

It is beyond the scope of this thesis to investigate the various methodologies for assessing socio-economic implications of biotech crops in any detail. However, Table 23.1 outlines some of the possible approaches and examples of considerations that such methods address.

Table 23.1. Research approaches for assessing socio-economic implications of genetically modified (GM) crops.

	Economic Modelling	Cost-Benefit Analysis	Social Impact Assessment	Sustainable Livelihood Framework	Systemic 'Relevance Assessment'	Participatory Research
Distribution of benefits	Which countries will benefit or lose from the adoption of a GM crop?	How are the costs and benefits created by the introduction of a given GM crop distributed among different groups in society?	Which people or groups will benefit or lose from the introduction of a given GM crop?	Which crops do different groups produce or need?	What is the problem to which GM crops respond? Who is affected by these problems and could benefit from the innovation?	Primary stakeholders – such as farmers – should be interviewed regarding whether and how they benefit from a GM crop.
Public sector R&D		How will different R&D approaches affect various institutions – both international ly and within countries?		What new types of crops would be most useful to farmers?	What types of R&D would produce innovations that address problems identified through a systemic relevance assessment?	Any public sector research on GM crops should be conducted in consultation with the end user, e.g. the farmer.
Labour	Which labour markets -- among and within countries – will be affected by the introduction of GM crops?	How will labourers and employees benefit or lose with the introduction of different GM crops?	Who performs the labour required for various crops? How would this change with the introduction of a given GM crop?	What labour requirement do various crops have, and who performs this labour?	If labour issues are identified as a problem, does a given GM crop help solve these problem?	Both agricultural labourers and employers can provide information about the impact of GM crops on labour supply and demand, and what types of labour are needed.

Markets (include issues of competition and niche markets, e.g. organic)	How will international trade agricultural goods be affected? Which countries might lose or gain export partners? Which countries may see increases or decreases in commodity prices?	Which crops or types of markets will see a gain or loss from the introduction of different GM crops? Who depends on these markets?		Which crops are kept for household consumption and which are sold on the market? How do prices for crops change throughout and between years?	What is the influence of markets on various agricultural systems and agricultural innovations? Does the main market system stimulate some innovations and create obstacles for others?	Farmers should be included to share information on how markets for particular agricultural products have changed with the introduction of GM.
Intellectual property rights	What are the economic implications -- e.g. costs of agricultural inputs and products – under various IPR regimes?	Are there any costs or benefits associated with IPRs that affect producers and/or consumers? How do researchers and companies involved in biotech benefit or lose from IPRs?	What will the positive and negative effects of IPRs be (e.g. on seed prices or domestic research), and who will be affected?	How are seeds obtained? What role, if any, does seed saving and/or sharing play?	Do some institutional frameworks (such as IPRs) have an influence on the commercial success of different innovations in solving a particular crop problem (e.g. disease, insect damage, weeds)?	Participatory research would enable the sharing of information regarding whether and how IPRs have affected farmers' access to seeds, and any legal issues that may arise from patents on GM seeds.
Public opinion	How does public opinion affect how markets function and which countries trade with each other?		What cultural values relevant to GMOs are held by communities that may be affected by the introduction of GMOs?			Research on public opinion is necessarily participatory in nature.

Ethics, culture and religion	Will some farmers and/or consumers lose control over their production and consumption choices as a result of GM crops?	Do affected communities hold ethical, cultural or religious beliefs that are violated by genetic engineering?		Members of the public, including farmers and consumers, can contribute to discussions on how their religion, culture, and/or ethical beliefs relate to GMOs.
Table adapted from Fransen *et al*., 2005.				

Limitations

Most of the methods for assessing SECs address a limited number of factors (for instance, cost-benefit analyses are less applicable to ethical and religious factors), thus should be used in conjunction to capture the full range of socio-economic impacts. Furthermore, many SECs are considered *ex ante*, which pose certain limitations. For instance, impact assessment of a yet-to-be-released technology under farming conditions is limited due to the lack of primary information; instead, the best available data is generated during confined field trials (CFTs) which also face certain challenges, such as difficulties in capturing the full range of agro-ecological and farming conditions (Horna *et al*., 2013). For example, the successful adoption of a biotech crop variety may vary greatly across locations and individual farms due to producer heterogeneity (e.g. differences in incidence and prevalence of pest and disease). Including such heterogeneity in *ex ante* studies is challenging and homogeneity bias may be introduced as a result (Horna *et al*., 2013). Additionally, certain assumptions have to be made in terms of the size and value of each variable included in the analytical model (Horna *et al*., 2013). Furthermore, *ex ante* impact assessments are often carried out over a short time frame due to time and budget constraints, which limit the ability to capture the impact that climatic and environmental variability may have on the outcome (Ludlow *et al*., 2014). Finally, socio-economic impacts may be influenced by production and market factors that appear *ex post*. Consequently, it may be necessary to incorporate in-depth studies during the initial stages of commercialisation to uncover any potential bottlenecks (Horna *et al*., 2013).

Part E: Awareness, Attitudes, Perceptions and Acceptance of Genetically Modified Crops among East African Stakeholders and Farmers

Chapter 24. Social Science Study: Awareness, Attitudes, Perceptions and Acceptance of Genetically Modified Crops among East African Stakeholders and Farmers

24.1. Introduction

The attitudes and intentions of stakeholders representing public and private interests in the GMO debate can have a significantly influence on public perceptions, as well as on policy and decision-making outcomes (Aerni & Rieder, 2001; Aerni, 2005). However, whereas the debate has largely been dominated by researchers, governmental and policy officials, agricultural economists, development experts and NGOs, the voice of the East African farmer have been more or less muted (Schnurr & Mujabi-Mujuz, 2014). Still, consumer awareness and demand – including those at the start of the supply chain (i.e. the farmers) and at the end (i.e. the net consumers) – is a major determinant for the successful widespread adoption of new crop varieties (Tripp, 1996; Fewer *et al*., 1998; Bett *et al*., 2010; Kagai, 2011; Kimenju *et al*., 2011; Ainembabazi *et al*., 2015). Consequently, it has been argued that farmers should be engaged across the whole process of developing a GM product (Bailey *et al*., 2014). Thus, an important consideration for the introduction of any novel technology is the prevailing attitudes, perceptions and acceptance of the technology that exist among farmers and various stakeholders; the underlying behavioural mechanisms; and how perceptions might change in response to various factors.

Factors influencing attitudes, perceptions and acceptance of genetically modified organisms (GMOs)

Attitudes, perceptions and acceptance of GMOs involve multiple factors (Fig. 24.1), including (i) awareness (e.g. Pew Initiative on Food and Biotechnology, 2001a); (ii) basic knowledge of the underlying technology (e.g. Grobe *et al*., 1999; Gaskell *et al*., 2006; Gurudasani & Sheth, 2009); (iii) how new information is perceived, learnt and processed (e.g. Costa-Font *et al*., 2008; Smale *et al*., 2009; Kagai, 2011); (iv) perceived risks and benefits to humans, animals and the environment (e.g. Bredahl *et al*., 1998; Bredahl, 2001; Moon & Balasubramanian, 2001; Harrison *et al.*, 2005; Han & Harrison, 2007); (v) demographic factors such as level of education, income, age and sex (e.g. Hwang *et al*., 2005; Gaskell *et al*., 2006; Capalbo *et al.*, 2015); (vi) cultural habits, religion and ideology (Moon & Balasubramanian, 2001; Han & Harrison, 2005; Scheitle, 2005); (vii) level of trust in governments and regulatory decision-makers, biotech companies and private multinationals, and research stations and institutions (e.g. Moon & Balasubramanian, 2001; Hossain *et al*., 2002; James, 2003; House *et al*., 2004; Barnett *et al*., 2007; Peters *et al*., 2007; Capalbo *et al*., 2015); and (viii) product characteristics such as price, yield performance, storability, food preparation, taste and appearance (see Box 24.2 for an example) (e.g. Fransen *et al*., 2005; Ezezika *et al.,* 2012; Schnurr & Mujabi-Mujuz, 2014).

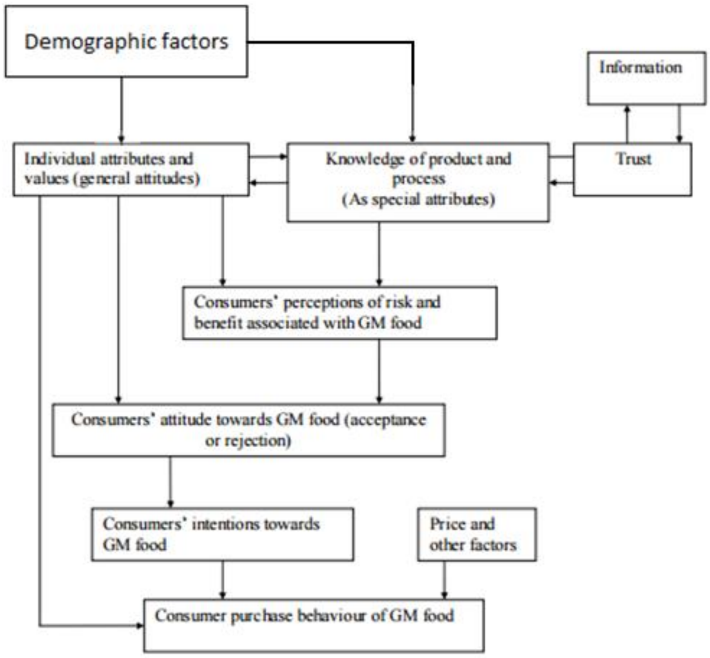


Figure 24.1. Possible factors and processes influencing acceptance of genetically modified (GM) food products by consumers. The diagram could also apply to farmer attitudes, intentions and adoption behaviour of GM seeds and planting material. "Price and other factors" could refer to yield performance, storability, food preparation, taste and appearance. Figure adapted from: Costa-Font, 2009.

Previously conducted perception studies in the East African region

A study found that the majority of urban and rural consumers in Nairobi and Eastern Kenya were unaware of GM crops (38% and 31% were aware, respectively), while only 12.7% of farmers were aware of the technology (note that the surveys were conducted at various stages, i.e. in 2002, 2003 and 2006) (Kimenju & Groote, 2008; Kimenju *et al*., 2011). Despite the relatively low awareness, the majority of participants displayed positive perceptions of the technology and a high willingness-to-buy GM maize meal at even premium prices (though such findings may reflect factors such as hypothetical bias; see Box 24.1), even when such participants expressed concerns related to, amongst others, the environment and biodiversity. Kimenju & Groote (2008) further demonstrated a positive relationship between awareness and level of education and income among urban consumers in Nairobi.

Box 24.1. Hypothetical bias. Studies on consumer behaviour, such as those investigating willingness-to-pay and willingness-to-grow, may experience hypothetical bias. Hypothetical bias describes a tendency of participants to misrepresent their true opinions, often on the basis of believing that a certain product may be commercialised sooner if a higher likeness of a product is expressed than is actually the case (Lusk, 2003). One could imagine hypothetical bias applying to the GMO opposition as well, whereby negative opinions are exaggerated in hopes of preventing adoption. Lusk (2003) suggests using "cheap talk" to avoid such bias, whereby participants are made aware of the phenomenon (note that "cheap talk" was not employed during the perception studies conducted for the purpose of this thesis).

Consistent with Kimenju & Groote (2008) and Kimenju *et al*. (2011), a 2007/2008 study by Njoka *et al*. (2011) demonstrated a high level of positive perceptions among a range of stakeholders across all eight Kenyan provinces, including the general public, farmers, academics and resource persons/scientists. The study further found that men and younger age groups, as well as those residing in low or medium potential agro-ecological zones (AEZ), were most positively inclined. A study by Kagai (2011) also found that female farmers in the Trans-Nzoia county of Kenya, and those that perceived GM crops as high risk/low benefit, were more likely to disapprove GM crop products. Contrary, those that possessed basic knowledge of biotech crops and had an understanding of government policies were more likely to approve.

A 2007 study conducted among Ugandan consumers found a high willingness-to-buy transgenic bananas at the same price as conventional ones (consistent with Ainembabazi *et al*., 2015; Box 24.2) on the basis of three traits – i.e. agronomic (disease resistance), nutritional and taste (Kikulwe *et al*., 2011). Interestingly, the study found that willingness-to-buy depended on the trait in question and demographic factors. For instance, willingness-to-purchase decreased with an increase in education level for all three traits, while those with a high income were less willing to buy GM bananas for agronomic traits, but were more likely to do so for nutritional and flavour traits. Elderly and female respondents were generally less willing to buy transgenic bananas with enhanced taste, while sole consumers were more likely to buy bananas with nutritional benefits as opposed to producers. Furthermore, there were geographical differences – respondents from the Central and Eastern region were less likely to purchase GM bananas exhibiting taste traits as opposed to the ones in the Southwestern region (which were more likely to be indifferent).

Box 24.2. Farmer awareness and perceptions of transgenic bananas resistant to Banana Xanthomonas Wilt (BXW). A study by Ainembabazi *et al*. (2015) found that 36% of the 75 respondents – including farmers, traders, extension agents and key informants from Burundi, the Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda – believed they knew the meaning of "genetically modified bananas"; ~42% defined it as "an improved banana with integrated gene(s) from other sources", ~35% defined it as "a banana which has been bred to resist diseases", and ~24% thought it was "a banana variety with different properties from local varieties (i.e. good eye appeal, but tasteless and with long-term health effects)". ~95% perceived BXW-resistant bananas as potentially advantageous, with "increase in income" reported as the biggest benefit. However, 40% also perceived the GM bananas as having negative consequences, with "outbreak of new diseases due to mutations and loss of local varieties" being considered the major disadvantages.

Furthermore, 31% of the surveyed farmers preferred local varieties over BXW-resistant bananas as these were perceived as tastier and easier to cook. Aesthetics and quality were more important for consumers' willingness-to-buy than whether or not it was transgenic. Additionally, price and quality were the most deterministic factors on whether or not to purchase GM bananas, and 78-92% of consumers were willing to buy at the same price as conventional ones.

In Tanzania, a 2009 study conducted in three districts near Dar es Salaam found that farmer awareness and knowledge of the underlying technology of biotech crops, as well as its potential risks and benefits, was very low (Lewis *et al.,* 2010). This finding is consistent with Mneney, 2003 (as cited by Lewis *et al.,* 2010). A study conducted by the Vice President's Office found awareness to be as low as 0.85% among farmers and 32.7% among other stakeholders (i.e. academia, regulatory authorities, service providers, NGOs, the media and farmers) (United Republic of Tanzania, 2012). The majority of respondents believed that the potential risks outweighed the potential benefits of the technology, though most failed to provide valid examples of such risks (e.g. potential loss of indigenous species, health implications, and development of resistant pests). The study further found that education had a positive impact on awareness, while men and younger respondents were found to be more aware, knowledgeable and/or acceptant of biotechnology. Finally, respondents of the Eastern zone ("Morogoro") were more well-informed than those from the Central ("Dodoma") and Northern ("Same") regions, which was believed to reflect the presence of higher learning institutions and previously conducted awareness training and workshops.

However, a recently conducted study showed that the average level of awareness of GM crops and foods was 49.1% among various Tanzanian stakeholders (i.e. regulatory authorities, academics, the media and farmers) (Mnaranara *et al*., 2017). More specifically, the level of awareness was 24.0% among farmers. The study further showed that regulatory authorities and academics expressed positive opinions of GM foods, while farmers and the media exhibited more concerns associated with the technology (e.g. potential health risks and ethical misgivings).

The aims and hypotheses of the present study

The present study was conducted in order to assess (i) the level of awareness, attitudes,perceptions and acceptance of GM crops among stakeholders from Kenya, Uganda, Tanzania and Ethiopia, including agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, and civil servants employed in a non-governmental organisation, as well rural farmers from the former three countries; (ii) in what way awareness and attitudes might have changed since previously conducted perception studies; and (iii) potential factors that may impact on the attitudes and perceptions of biotech crops and product thereof, and further help explain the observed differences and similarities within and between study countries.

As the GMO debate has gained wider public advocacy in all study countries in recent years, it would be natural to assume that there has been an increase in the level of awareness since previously conducted perception studies. One could further hypothesise that countries with a longer history of practical experience dealing with agricultural biotechnology exhibit the highest level of awareness of, and positive attitudes towards, the technology. Based on this assumption, one would expect Kenyan and Ugandan stakeholders and farmers to be the most aware and positively inclined, while those from Tanzania and Ethiopia would exhibit comparably lower levels of awareness and less favourable attitudes.

Factors which are hypothesised to influence awareness, attitude and acceptance include demographic attributes such as sex, age, education, income level, cultural leaning, family background, occupational group and farm size; the general attitude towards agricultural biotechnology; risk/benefit perception; source(s) of information on biotech crops; and the effect of basic knowledge and acquisition of novel information about the technology.

24.2. Materials and methods

24.2.1. Development and lay-out of the Stakeholder and Farmer questionnaires

The questionnaires were developed in cooperation with Dr. Shiferaw Feleke (agricultural economist, IITA Tanzania) and Dr. Victor Manyong (agricultural economist and Director of IITA Eastern Africa and Leader of the social science research group of IITA).

Two types of structured questionnaires were developed: (i) a farmer questionnaire to map awareness, perception and demand for GM crops among farmers in Kenya, Uganda and Tanzania (Appendices 1, Appendix A) (from now on referred to as the Farmer questionnaire); and (ii) a questionnaire to map the attitudes and perceptions of stakeholders with a professional involvement in the GMO debate (from now on referred to as the Stakeholder questionnaire) (Appendices 1, Appendix B), including researchers, civil servants employed in public/private sector either related or not related to agriculture, civil servants in non-governmental organisations, extension workers, policymakers, and others (including a representative from the media and a biosafety regulatory expert for the Africa region).

Additionally, the final section of both questionnaires contained a set of demographic questions, including nationality, age, sex, level of education, cultural leaning, religious background and marital status. Farmers were also asked about farm size in hectares, while the other stakeholders had to answer additional questions concerning family background, upbringing, income level and occupation.

24.2.2. Farmer surveys: Data collection

The perception studies conducted among Kenyan and Ugandan farmers were funded by the Norwegian University of Life Sciences (NMBU) and were carried out with the aid of the organisation the Integrated Community Organization for Sustainable Empowerment and Education for Development (ICOSEED). In Tanzania, the survey was conducted by a team lead by Mr. Julius Nyalusi from the Ministry of Agriculture, Livestock and Fisheries on behalf of, and funded by, NMBU/IITA Tanzania.

The surveys were carried out at local meeting places or at the homes of village leaders or contact farmers. Farmers were given information orally about the objective and aim of the study, after which they had to sign a consent form on behalf of the team carrying out the data collection. However, the data were completely anonymous when handed over for analyses, i.e. the participants could not be identified directly or indirectly.

The questions were read aloud in the local language, after which a show of hand, as well voiced opinions, comments and elaborations, were recorded. The data collection team stressed that there were no right or wrong answers, and that farmers should speak freely and without fear. Farmers were allowed to elaborate on their opinions and definition of GMOs before being given the definition set by the thesis (i.e. *plants modified by genetic engineering technique to enhance desirable characteristics such as high yielding capacity, increased resistance to drought, diseases, pests").*

Personal participation took place on the first and last day of the first week of data collection in Kenya.

24.2.3. Kenyan field survey

72 farmer groups with an average of 15-16 farmers were surveyed between the 7th and 28th of November 2016. At the end of the survey, a total of 1127 farmers had participated. The survey sites included the counties Embu, Kiambu, Kirinyaga, Kitui, Machakos, Makueni, Meru, Muranga, Nyeri and Tharaka-Nthi (Fig. 24.2).

A pre-test of the questionnaire was carried out on farmer groups nearby the ICOSEED office in Kutus, which offered a chance for the data collection team to familiarise themselves with the questionnaire, as well as optimise the execution of the survey (e.g. determining the target number of farmers).

Figure 24.2. Map of Kenya. The Kenyan farmer survey included farmer groups from the counties Embu, Kiambu, Kirinyaga, Kitui, Machakos, Makueni, Meru, Muranga, Nyeri and Tharaka-Nthi. Figure provided by ICOSEED.

The majority of participants were rural poor with a land holding from between <0.5 to >5.0 hectares (ha) depending on the location, with the average being 1.0-1.9 ha. Farmer cultivated a range of crops, including beans, cotton, maize, bananas and rice. ~59% of farmers were women, ~91% were married, and the age ranged from 19 to 80 y/o (Table 24.1). ~54% of farmers had achieved primary education, while ~38% and ~8% had achieved secondary and higher education (most with some college, while a few had Bachelor and Master degrees), respectively (Table 24.1). All but five farmers were Christians (Table 24.1), while most farmers considered themselves moderate in terms of cultural leaning (~79%), followed by liberal (~19%) and conservative (~2%) (Table 24.1).

Table 24.1. Demographic profile of surveyed Kenyan farmer groups divided by county.

County [no. of farmers]	Gender (female: male)	Age	Education	Marital status	Religion	Cultural leaning	Farm size (hectares, ha)
Embu [70]	19:21	45-60	46 secondary, 14 higher	All married	1 Muslim, remaining Christians	10 liberal, 60 moderate	0.5-3.9 (most common 1.9-2.9)

Kiambu [71]	41:30	25-70	19 primary, 40 secondary, 12 higher	10 single, 50 married	All Christians	4 liberal, 67 moderate	<0.5-0.9
Kirinyaga [126]	65:60	25-70	35 primary, 35 secondary, 14 higher	13 single, 73 married	All Christians	126 moderate	Most commonly 0.5-3.9
Kitui [61]	24:37	34-67	17 primary, 3 secondary	All married	All Christians	63 moderate	<0.5-2.9 (most common 1.0-1.9)
Machakos [150]	131:19	30-75	68 primary, 16 secondary, 14 higher	6 single, 144 married	All Christians	93 moderate, 19 conservative	Most commonly 4.0-4.9
Makueni [75]	62:13	25 to >40	18 primary, 19 secondary, 2 higher	10 single, 40 married	All Christians	71 liberal, 4 moderate	1.0-1.9
Meru [203]	70:133	20-80	128 primary, 80 secondary	16 single, 187 married	1 Muslim, remaining Christians	107 liberal, 89 moderate	<0.5
Muranga [72]	51:21	21-55	8 primary, 54 secondary, 10 higher	19 single, 53 married	All Christians	72 moderate	0.5-1.9
Nyeri [71]	29:41	19-63	22 primary, 37 secondary, 10 higher	11 single, 59 married	3 Muslims, remaining Christian	12 liberal, 59 moderate	1.0-1.9
Tharaka-Nithi [228]	145:83	25-60	194 primary, 33 secondary, 1 higher	8 single, 220 married	All Christians	228 moderate	50/50 <0.5 and 4.0-4.9
Total/ summary [1127]	667:459 (~59% females, ~41% males)	19-80	509 primary (~54%), 363 secondary (~38%), 77 higher education (~8%)	93 single (~9%), 949 married (~91%)	1122 Christian (~99.5%), 5 Muslims (~0.5%)	204 liberal (~19%), 861 moderate (~79%), 19 conservative (~2%)	Most common <0.5->5.0

Note: Percentages were calculated on the basis of the number of respondents (not the total number of farmers).

24.2.4. Ugandan field survey

10 farmer groups (with 10-18 farmers in each) and a total of 142 farmers were surveyed between the 7th and 13th of December 2016. The survey areas included the districts of Wakiso, Mukono, Mpigi and Luwero (Fig. 24.3) (note that Ugandan districts are considered the same as Kenyan counties). Before commencing, the data collection team was given information about the socio-cultural norms and the agricultural background and dynamics of rural Ugandan farming communities over the past decade, and a pre-test was carried out on the 7th of December 2016.

Figure 24.3. Map of Uganda. The Ugandan farmer survey included farmer groups from the districts Wakiso (not shown, indicated by arrow), Mukono, Mpigi and Luwero. Figure from: Uganda Travel Guide, s.a.

Farmers were rural poor with an average land holding between <0.5-1.0 ha (the total ha varied as many farmers rented land). The crops cultivated included coffee, maize, bananas, potatoes, cowpea, pigeon pea, and vegetables like kale and spinach. ~62% of farmers were women, ~73% were married, and the age ranged from 17 to 80 y/o (Table 24.2). ~62% had primary education, followed by secondary (~26%), higher (~9%) (most of whom had some college and a few with Bachelor degrees) and no education (~3%) (Table 24.2). ~86% identified themselves Christian, ~1% as Muslims and ~4% as traditional (Table 24.2). ~48%, ~38% and ~14% considered themselves as moderate, conservative and liberal in terms of cultural leaning, respectively (Table 24.2).

Table 24.2. Demographic profile of surveyed Ugandan farmer divided by groups.							
Group number [no. of farmers]	**Gender (female: male)**	**Age**	**Education**	**Marital status**	**Religion**	**Cultural leaning**	**Farm size (hectares, ha)**
1 [16]	13:3	24-60	4 no education, 5 primary, 5 secondary, 2 "higher"	4 single, 12 married	15 Christians, 1 Muslim	All conservative	1.0
2 [13]	11:2	23-80	10 primary, 3 secondary,	4 single, 8 married	All Christians	All conservative	0.5-1.0
3 [11]	1:10	18-78	4 primary, 4 secondary, 3 "higher"	5 single, 6 married	10 Christians, 1 Muslim	1 liberal, 1 moderate, 9 conservative	1.0
4 [12]	11:1	23-80	11 primary, 1 secondary	All married	10 Christians, 2 Muslims	All moderate	1.0
5 [16]	11:5	17-65	10 primary, 6 secondary	8 single, 8 married	15 Christians, 1 Muslim	All conservative	<0.5
6 [16]	9:7	N/A	6 primary, 7 secondary, 3 "higher "	7 single, 9 married	8 Christians, 2 Muslims, 6 traditional	All moderate	0.5
7 [11]	7:4	25-70	7 primary, 1 secondary, 3 "higher"	3 single, 8 married	All Christians	All moderate	<0.5-1.9
8 [10]	5:5	40-70	4 primary, 4 secondary, 2 "higher"	3 single, 7 married	All Christians	All moderate	<0.5
9 [19]	13:6	N/A	17 primary, 2 secondary	1 single, 18 married	16 Christians, 3 Muslims	All liberal	<0.5
10 [18]	9:9	N/A	14 primary, 4 secondary	3 single, 15 married	14 Christians, 4 Muslims	All moderate	<0.5-0.9
Total/ summary [142]	88:54 (~62% females, ~38% males)	17-80	4 no education (~3%), 88 primary (~62%), 37 secondary (~26%), 13 "higher" (~9%)	38 single (~27%), 103 married (~73%)	122 Christians (~86%), 14 Muslims (~10%), 6 traditional (~4%)	20 liberal (~14%), 68 moderate (~48%), 54 conservative (~38%)	Most common <0.5-1.0
Note: Percentages were calculated on the basis of the number of respondents (equalled to the total number of farmers). Note: N/A = no answer.							

24.2.5. Tanzanian field survey

85 farmer groups (with an average of 9 farmers each) from the districts Karatu (in the Arusha region) and Babati (in the Manyara region) (Fig. 24.4) were surveyed between the 23rd and 31st of January 2017. At the end of the study, a total of 805 farmers had been surveyed. Before commencing, three enumerators with experience in data collection and field work were allowed to familiarise themselves with the questionnaire.

Figure 24.4. Map of Tanzania. The Tanzanian farmer survey included farmer groups from the districts Karatu and Babati in the Arusha and Manyara regions, respectively. Figure from: United Republic of Tanzania, 2010b.

Land holdings varied from <0.5 to >5.0 ha, with the average being 2.0-2.9 ha. Farmers cultivated a range of crops, including maize, pigeon pea and beans. Paddy rice was cultivated in areas with available irrigation schemes (e.g. the Kigugu area in Babati). ~58% of the farmers were male, ~93% were married, and the age varied from 17-83 y/o (Table 24.3). ~89% of farmers had achieved primary level education, ~8% secondary level education and ~3% had higher education (the majority of whom had some college, while a few had Bachelor degrees and even PhDs) (Table 24.3). ~66% were Christians, while ~34% were Muslims (Table 24.3). ~89% defined themselves as moderate culturally, while ~10% and ~1% defined themselves as liberal and conservative, respectively (Table 24.3).

Table 24.3. Demographic profile of surveyed Tanzanian farmer groups divided by district.							
District (region) [total no. of farmers]	**Gender (female: males)**	**Age**	**Education**	**Marital status**	**Religion**	**Cultural leaning**	**Farm size (hectares, ha)**
Karatu (Arusha) [231]	82:136	28-71	210 primary, 12 secondary, 2 higher	13 single, 208 married	22 Muslims, 208 Christians	34 liberal 189 moderate	Most common 2.0-2.9
Babati (Manyara) [574]	245:324	17-83	193 primary, 53 secondary, 20 higher	41 single, 534 married	225 Muslims, 318 Christians	46 liberal, 522 moderate, 6 conservative	Most common 2.0-2.9
Total/ summary [805]	327:460 (42% females, 58% males)	17-83	703 primary (~89%), 65 secondary (~8%), 22 higher education (~3%)	54 single (~7%), 742married (~93%)	277 Muslims (~34%), 526 Christians (~66%)	80 liberal (~10%), 713 moderate (~89%), 6 conservative (~1%)	Most common 2.0-2.9
Note: The percentages were calculated based on the number of respondents (not the total number of farmers).							

24.2.6. Stakeholder survey: Data collection

Data collection for the Stakeholder survey commenced on the 1st of January 2017 and continued until mid-February. Potential participants were selected on the background of their involvement in the topic of agricultural biotechnology in East Africa, and were identified through internet-based searchers or through contacts situated at NMBU, ILRI, IITA and so forth.

Most commonly, the stakeholders were first contacted via email either directly, by reference, or through a contact person. The email informed of the aim of the survey and the importance of the participant's contribution. Seeing as the chosen stakeholders were involved in the topic, it was assumed that the findings would also be of interest to them. If the stakeholder agreed to participate, he or she was sent the questionnaire as a pdf and word file. In a few cases, the questionnaires were handed over personally.

The questionnaire contained further information about the objective and aim of the study (Appendices 1, Appendix B). Subsequently, participants had to sign a consent form stating that they understood what participation involved in terms of privacy and confidentiality, withdrawal from the study, storage of data after completion of the survey, etc. (Appendices 1, Appendix B).

The aim was to acquire 25 respondents from each stakeholder group divided on the four study countries (i.e. 6-7 agricultural researchers, 6-7 policymakers, 6-7 civil servants from NGOs, and so forth from each respective country) (Feleke, pers. comm.). A larger sample size was not considered necessary as replies were expected to be rather predictable on the basis of the participants' professional background (Feleke, pers. comm.). A total of 135-140 stakeholders were contacted, whereby 78 respondents completed the questionnaire (i.e. ~56-57% response rate). Consequently, the target number for each study country was not achieved (Table 24.4).

Table 24.4. Nationality and occupation of surveyed stakeholders in number of respondents.

	Kenya	Uganda	Tanzania	Ethiopia	Total
Farmer[1]	3	0	0	0	3
Agricultural researcher	10	2	2	7	21
Agricultural extension personnel	7	1	3	0	11
Policymakers	2	0	0	0	2
Civil servant (1)	16	2	1	1	20
Civil servant (2)	1	0	1	0	2
Civil servant (3)	9	5	2	1	17
"Other"[2]	1	1	0	0	2
Total	49	11	9	9	78

Note: Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in a non-governmental organisation sector.

[1]This stakeholder group considered being a farmer as their main occupation, but had additional forms of professional involvement in the topic of agricultural biotechnology.

[2]"Other" included a representative from the media and a biosafety regulatory expert for the Africa region.

Most respondents were male (~70%), between the age of 30-49 (~64%), married (~86%), Christian (~97%), had achieved a Bachelor or Master degree (~65%), earned either between US$400-599/month (~25%) or >US$1000/month (~28%), and recognised themselves as moderate in terms of cultural leaning (~78%). See Table 24.5 for more demographic information.

Table 24.5. Demographic characteristics of surveyed stakeholders[1]; in % and [number] of respondents.

Sex	**Male**	**Female**				
	~70 [55]	~30 [23]				
Marrital status	**Married**	**Single**				
	~86 [66]	~14 [11]				
Religion	**Christian**	**Muslim**				
	~97 [76]	~3 [2]				
Cultural leaning	**Liberal**	**Moderate**	**Conservative**			
	~78 [61]	~22 [17]	0 [0]			
Knowledge about agriculture and rural life	**Not much**	**Know enough**	**Very knowledgeable**			
	~6 [5]	~41 [32]	~52 [41]			
Educational level	**Secondary**	**Some college**	**Bachelor**	**Master**	**PhD**	
	~5 [4]	~12 [9]	~31 [24]	~34 [26]	~18 [14]	
Age group (y/o)	**19-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**
	~8 [6]	~32 [24]	~32 [24]	24 [18]	~4 [3]	~1 [1]
Monthly income level	**<US$200**	**US$200-399**	**US$400-599**	**US$600-799**	**US$800-999**	**>US$1000**
	~4 [3]	~15 [11]	~25 [18]	~15 [11]	~13 [9]	~28 [20]
Type of upbringing	**Farm-family**	**Non-farm family**		**Rural village**	**Small town**	**City**
	~81 [63]	~19 [15]		~51 [40]	~30 [23]	~19 [15]

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not relate to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
Note: In cases where the number/percentage do not add up to the total, it is a result of participants leaving the question blank.
Note: The total number of participants was 78.

For the remainder of the thesis, “civil servants (1)” will refer to “civil servants employed in the public/private sector related to agriculture”, “civil servants (2)” will refer to “civil servants employed in the public/private sector not related to agriculture”, while “civil servants (3)” will refer to “civil servants employed in a non-governmental organisation”.

Perception groups. For convenience of analysis, stakeholders were grouped into one of four perception groups based on what they responded to the question "how much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country?" (Fig. 24.5):

(i) **Perception group 1 (PG1) [18 stakeholders]:** Was made up of those that were "negative" towards GM crops (i.e. "strongly disagree"). This group consisted mainly of civil servants in a non-governmental organisation (~67%) [12], followed by extension workers (~11%) [2], agricultural researchers (~5.5%) [1], civil servants (1) (~5.5%) [1], civil servants (2) (~5.5%) [1] and "other" (~5.5%) [1]. The group consisted of nine Kenyans (50%), four Ugandans (~22%), four Tanzanians (~22%) and one Ethiopian (~6%).

(ii) **Perception group 2 (PG2) [4 stakeholders]:** Was made up of those that were "somewhat positive" towards GM crops (i.e. "somewhat agree"). This was the smallest perception group with only four respondents, all from different occupational groups (i.e. a farmer, an agricultural researcher, a civil servant (1) and a civil servant (2). The groups consisted of three Kenyans (75%) and one Tanzanian (25%).

(iii) **Perception group 3 (PG3) [20 stakeholders]:** Was made up of those that were "positive" towards GM crops (i.e. "agree"), for which the major occupational group was civil servants (1) (45%) [9], followed by agricultural researchers 25% [5], extension workers 15% [3], a policymaker 5% [1], a civil servant (3) 5% [1] and "other" (5%) [1]. The group consisted of twelve Kenyans (60%), three Ugandans (15%), three Tanzanians (15%) and two Ethiopians (10%).

(iv) **Perception group 4 (PG4) [35 stakeholders]:** Was made up of those that were "very positive" towards GM crops (i.e. "strongly agree"). The group consisted in large parts of agricultural researchers ~ 40% [14] and civil servants (1) ~26% [9], followed by extension workers ~14% [5], civil servants (3) ~11% [4], farmers ~6% [2] and a policymaker ~3% [1]. The group consisted of 24 Kenyans (~69 %), six Ethiopians (~17%), four Ugandans (~11%) and one Tanzanian (~3%).

Note that one respondent did not answer the above-mentioned question, thus could not be placed in a perception group (referred to as "no PG").

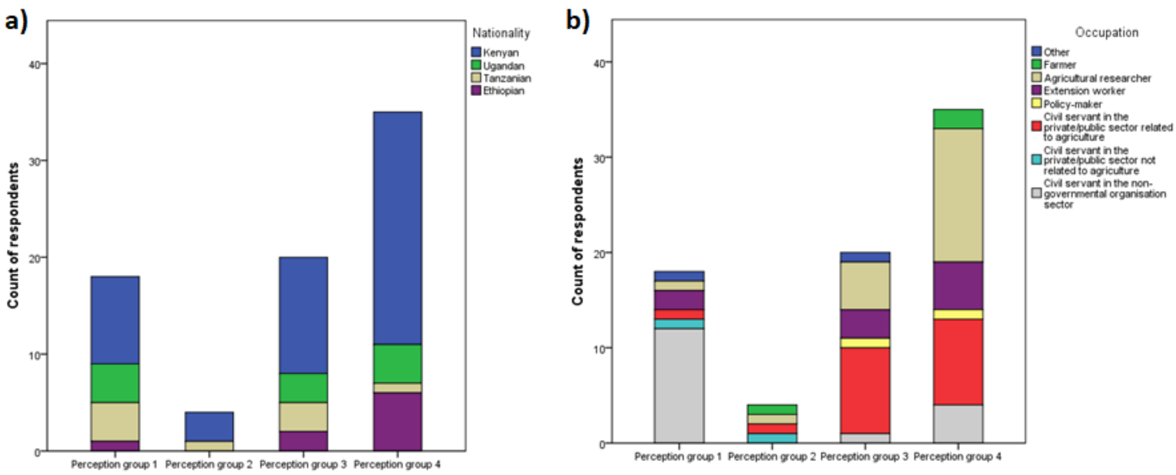


Figure 24.5. Composition of stakeholder perception groups (PG) in terms of a) nationality and b) occupational groups. PG1 = negative towards GM crops; PG2 = somewhat positive towards GM crops; 3 = positive towards GM crops; 4 = very positive towards GM crops. Response rate: ~99% (77 out of 78 participants).

24.2.7. Interviews

Interviews were carried out with Dr. Richard Okoth Oduor (senior lecturer, Department of Biochemistry and Biotechnology, Kenyatta University, Nairobi, Kenya) on the 29.09.16, Dr. Faith Nguthi (senior programme officer at ISAAA, *Afri*Center, Nairobi, Kenya) on the 31.08.16, and Dr. Dawit Tesfaye Degefu (molecular plant biotechnologist/molecular entomologist at the Ethiopian Institute of Agricultural Research) on the 19.10.16 (written interview). All of those interviewed gave a written consent where they agreed to their opinions being reiterated in the present thesis, and with their full name disclosed.

24.2.8. Data analysis

Farmer questionnaire

Firstly, the data was organised in an excel spread sheet, whereby each row represented one farmer group. For each response category, the number of respondents was plotted (Appendices 1, Table C.1). Subsequently, descriptive statistics, charts and percentage levels were produced using Microsoft Excel 2010 in order to assess the level of awareness, attitudes and perceptions.

The possible effects of geographical location on farmer responses (i.e. on the county-level in Kenya, on the district-level in Tanzania, and between study countries) were investigated using a Monte Carlo simulation model specifically developed by Professor Arne Huseby at the Department of Mathematics at the University of Oslo (Huseby *et al*., unpublished data) (Chapter 25, section 25.2.4). Note that it was not possible to discern any geographical effects for the Ugandan survey as the farmer groups could not be distinguished based on location.

The model allowed one to determine whether a significant effect existed, but not what the significance consisted of or the most important effects. Thus, for the purpose of investigation such aspects, descriptive statistics (i.e. bar charts and percentage levels) were used. However, one has to be cautious when drawing any conclusions based on such assessments, and more thorough statistical tests are needed to determine if such evaluations holds true or not.

The correlations between various x and y variables, including the correlation between demographic factors and awareness, perceptions and acceptance of GM crops (i.e. in the form of willingness-to-grow and support for commercialisation), as well as the relationships between awareness, perceptions and acquisition of new information, were investigated using another Monte Carlo simulation model specifically developed by Professor Arne Huseby (Huseby *et al*., unpublished data) (Chapter 25, section 25.1.5.3).

Due to the large amount of data, only findings of the greatest interest will be reported (for all results, please refer to Appendices 1, Appendix D).

Stakeholder questionnaire

Firstly, the data was organised in an excel spread sheet, whereby each row represented one respondent. The responses of each participant were plotted as numerical/categorical values (Appendices 1, Table C.2). Subsequently, descriptive statistics, charts and percentage levels were produced using IBM SPSS Statistics 21.

The possible effects of demographic factors on stakeholder opinions were evaluated using the same simulation model for investigating the potential geographical effects on farmer responses. As touched upon, the model did not provide information about what the significance consisted of or the most important effects, thus descriptive statistics (i.e. cross-tables and charts) were employed for this purpose.

Due to the large amount of data, only findings of the greatest interest will be reported (for all results, please refer to Appendices 1, Appendix E).

24.3. Results: Farmer surveys

The following three subchapters will consider the results obtained from the perception studies conducted among Kenyan, Ugandan and Tanzanian farmers.

24.3.1. Results from the Kenyan farmer survey

Results from the investigation of geographical effects on farmer responses are summarised towards the end of the subchapter.

Awareness of genetically modified (GM) crops

The level of awareness of GM crops was 100% in Muranga, 96% in Embu, 90% in Kirinyaga, 82% in Kitui, 77% in Nyeri, 75% in Machakos, 75% in Kiambu, 73% in Makueni, 76% in Meru, and 30% in Tharaka-Nithi (Fig. 24.6). Thus, on average, 77% of Kenyan farmers were aware of GM crops.

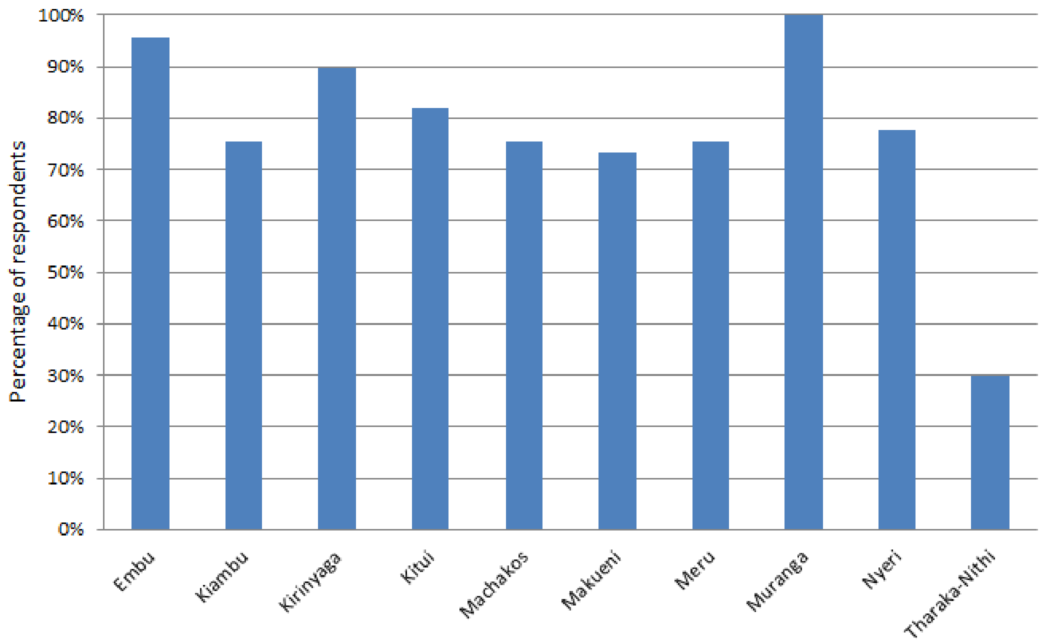


Figure 24.6. Level of awareness of genetically modified (GM) crops among Kenyan farmers across ten counties (in % of respondents). There were significant differences in the level of awareness across counties ($p<0.001$). Response rate: ~99% (1119 out of 1127 participants).

Impressions of genetically modified (GM) crops

In terms of the impression of GM crops, it was found that the observed number of respondents at times exceeded the expected number (i.e. the number of GMO aware farmers). Furthermore, without individually labelled data, it was challenging to determine to what extent the respondents consisted of those that were aware of GM crops. Thus, it was determined to calculate impressions on the basis of the number of respondents (note that this approach was also employed during data analysis for the Ugandan and Tanzanian surveys).

The level of favourable impressions of GM crops was 96% in Embu (3% unfavourable, 1% did not know), 92% in Kitui (8% unfavourable), 90% in Meru (10% unfavourable), 86% in Kirinyaga (10% unfavourable, 3% did not know), 82% in Makueni (18% unfavourable), 74% in Kiambu (26% unfavourable), 68% in Muranga (32% unfavourable), 64% in Nyeri (36% unfavourable), and 41% in Machakos (37% unfavourable, 22% did not know) (Fig. 24.7). None of the farmers in Tharaka-Nithi responded. Thus, an average of 77% of respondents had a favourable impression of GM crops, 20% had an unfavourable impression and 3% did not know.

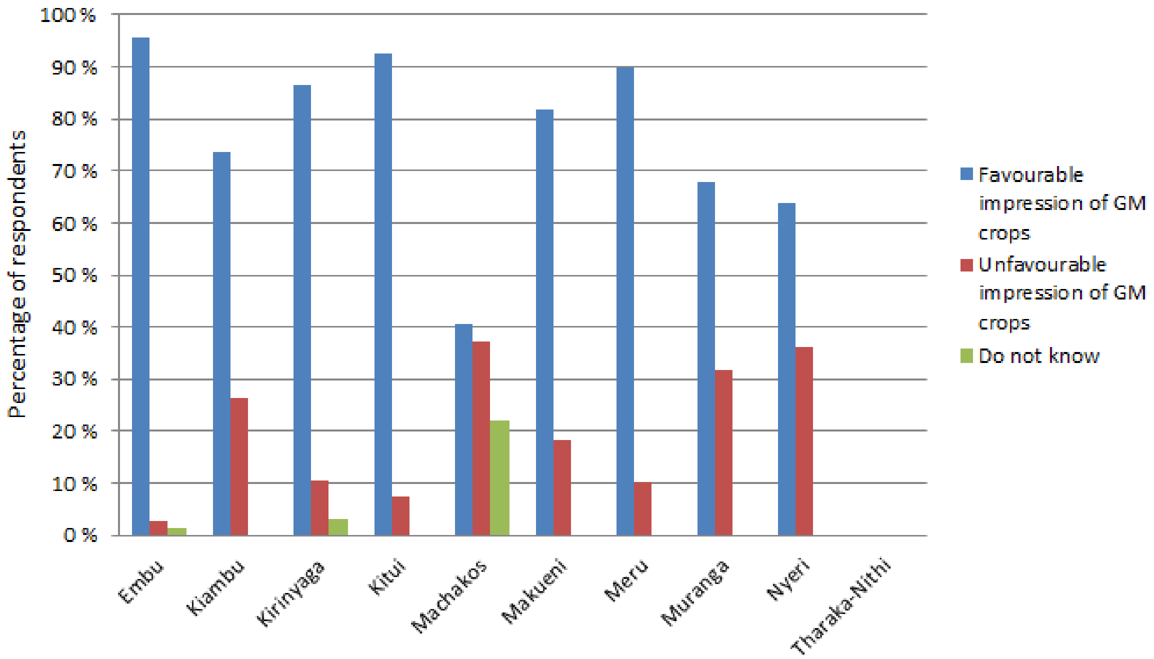


Figure 24.7. Impressions of genetically modified (GM) crops among Kenyan farmers across ten counties (in % of respondents). There were significant differences in farmer impressions across counties (p<0.001). Response rate: ~69% (783 out of 1127 participants). Note that the relatively low response rate was because the question was meant to presuppose awareness of GM crops.

Leading on from this, the percentage of farmers that believed farmers in their area had a favourable impression of GM crops, was 90% in Embu (1% believed they had an unfavourable impression, while 9% had no opinion), 78% in Kirinyaga (2% unfavourable, 19% no opinion), 75% in Kitui (12% unfavourable, 17% no opinion), 73% in Makueni (3% unfavourable, 12% no opinion), 73% in Tharaka-Nithi (3% unfavourable, 24% no opinion), 67% in Muranga (33% unfavourable), 58% in Meru (8% unfavourable, 34% no opinion), 54% in Kiambu (23% unfavourable, 23% no opinion), 42% in Machakos (39% unfavourable, 19% no opinion) and 35% in Nyeri (66% unfavourable) (Fig. 24.8). Thus, an average of 65% of farmers believed that farmers in their area had a favourable impression of biotech crops, 20% perceived them as having an unfavourable impression, while 16 % did not have an opinion.

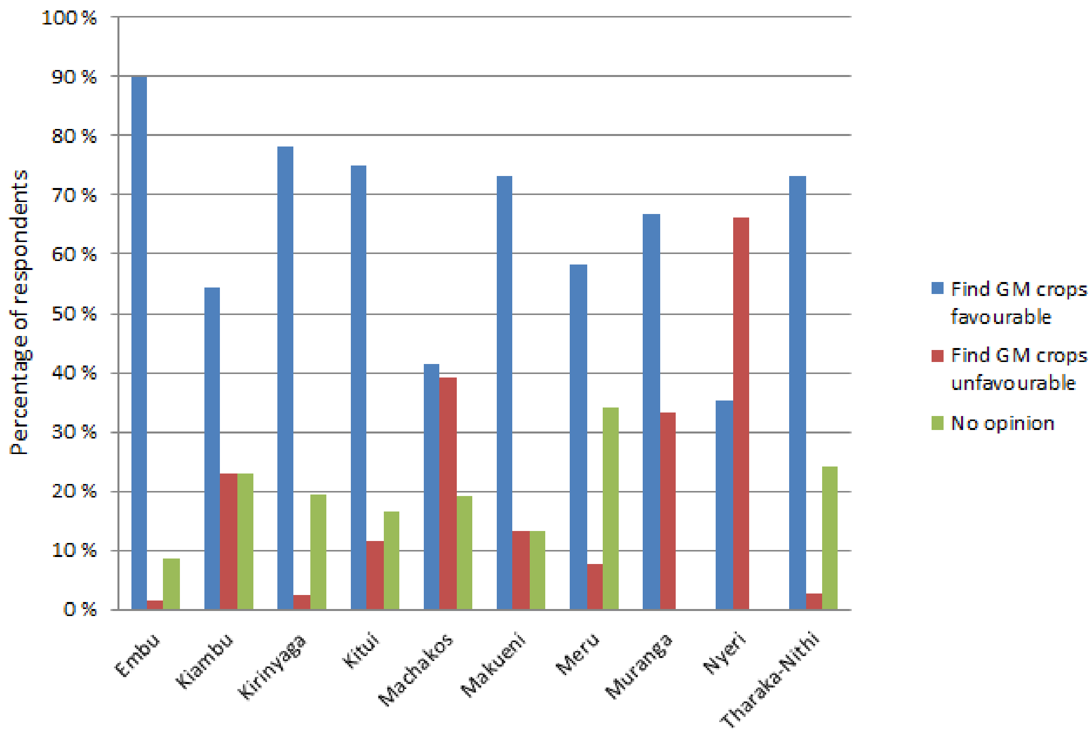


Figure 24.8. Percentage of Kenyan farmers across ten counties that believed farmers in their area had a favourable impression of genetically modified (GM) crops (in % of respondents). There were significant differences in farmer opinions across counties ($p<0.001$). Response rate: ~98% (1099 out of 1127 participants).

There was a significant correlation between the fraction of farmers that initially reported of a favourable impression of GM crops and the fraction that perceived farmers in their area as having a similar impression of the technology (Appendices 1, Table D.9.1). Contrary, the correlation between the fraction of farmers that had an unfavourable impression of the technology and the fraction of farmers that perceived farmers in their area as having an unfavourable impression was also significant and positive (Appendices 1, Table D.9.1).

Willingness-to-grow (WTG) genetically modified (GM) crops

Willingness-to-grow (WTG) GM crops was 99% in Kirinyaga (1% would not grow), 97% in Meru (3% did not respond; not shown in Fig. 24.9), 92% in Tharaka-Nithi (8% would not grow), 88% in Embu (3% would not grow, 9% did not know), 85% in Makueni (15% would not grow), 80% in Kiambu (7% would not grow, 13% did not know), 79% in Kitui (21% would not grow), 67% in Muranga (32% would not grow, 1% did not know), 64% in Machakos (36% would not grow), and 58% in Nyeri (42% did not know) (Fig. 24.9). Thus, on average, 81% of farmers would grow GM crops if given the opportunity, 16 % would not and 2 % did not know.

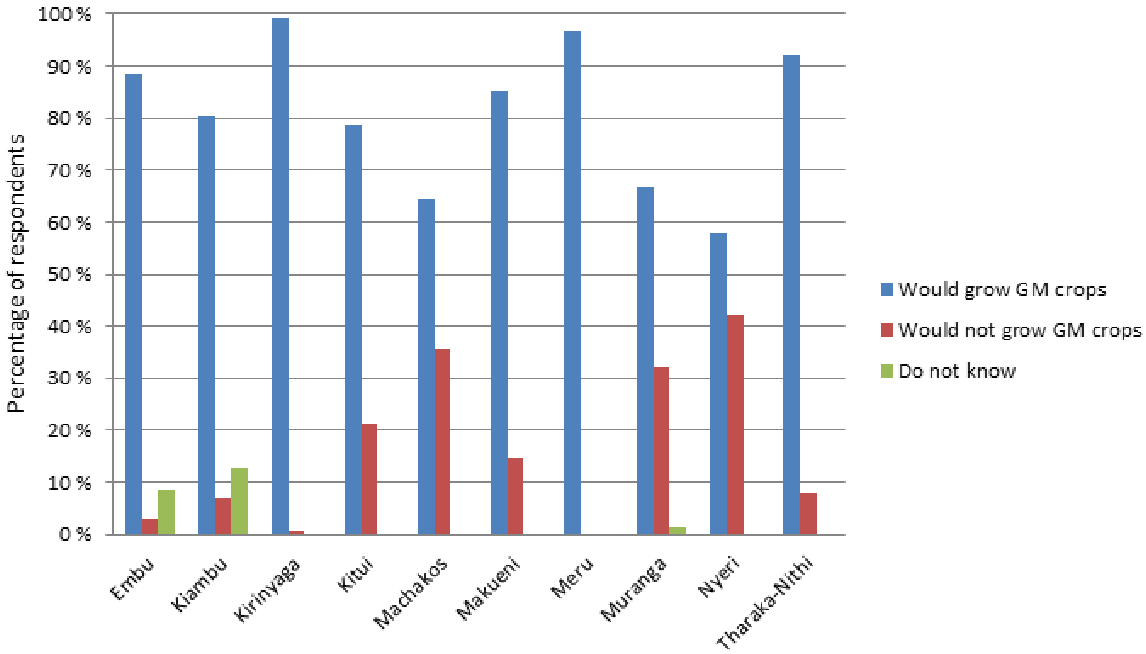


Figure 24.9. Willingness-to-grow (WTG) genetically modified (GM) crops among Kenyan farmers across ten counties. There were significant differences in WTG across counties ($p<0.001$). Response rate: ~99% (1121 out of 1127 participants).

The correlations between the fraction of farmers that had a favourable impression of GM crops and the fraction of farmers that were willing to grow, and between the fraction of farmers that had an unfavourable impression of the technology and the fraction not willing to grow, were positive and significant (Appendices 1, Table D.9.1).

Perceptions of the use of genetically modified (GM) crops to improve the quality of life of farmers

In response to the statement that GM crop could help improve the quality of life of Kenyan farmers, 100% believed this to be true in Kirinyaga and Makueni, 97% in Meru (3% did not respond; not shown in Fig. 24.10), 95% in Tharaka-Nithi (2% did not find the statement to be true, while 3% did not have an opinion), 90% in Embu (4% did not find the statement to be true, while 6% did not have an opinion), 89% in Kiambu (11% did not have an opinion), 79% in Kitui (21% did not have an opinion), 58% in Muranga (32% did not find the statement to be true), 48% in Nyeri (39% did not find the statement to be true) and 43% in Machakos (52% did not find the statement to be true, while 1% did not have an opinion) (Fig. 24.10). Thus, on average, 81% of farmers believed that GM crops could help improve the quality of life of Kenyan farmers, 13% did not find this statement to be true, while 4% did not have an opinion (2% did not respond).

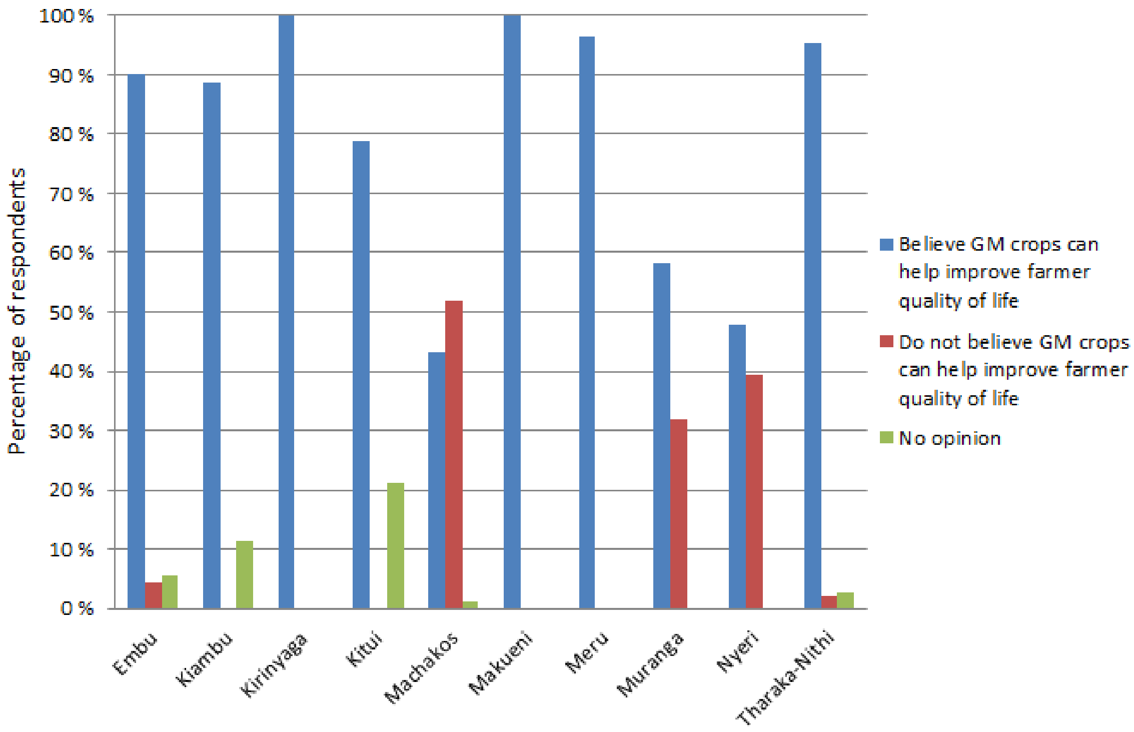


Figure 24.10. Percentage of Kenyan farmers across ten counties that believed genetically modified (GM) crops could help improve the quality of life of Kenyan farmers (in% of respondents). There were significant differences in farmer opinions across counties ($p<0.001$). Response rate: ~99% (1112 out of 1127 participants).

The correlation between the fraction of farmers that had a favourable impression of biotech crops and the fraction of farmers that believed GM crops could help improve the quality of life of farmers was positive and significant (Appendices 1, Table D.9.1). Contrary, there was a positive correlation between the fraction of farmers that had an unfavourable impression of biotech crops and the fraction that did not believe the technology could help improve the quality of life of farmers (Appendices 1, Table D.9.1).

The level of support for commercialisation of genetically modified (GM) crops

The level of support for the commercialisation of GM crops was 100% in Kiambu and Makueni, 97% in Meru (3% did not have an opinion), 95% in Kirinyaga (3% did not support commercialisation, while 2% did not have an opinion), 94% in Embu (6% did not have an opinion), 94% in Tharaka-Nithi (6% did not support commercialisation), 84% in Kitui (16% did not support commercialisation), 71% in Machakos (27% did not support commercialisation, while 2% did not have an opinion), 67% in Muranga (34% did not support commercialisation), and 48% in Nyeri (52% did not support commercialisation) (Fig. 24.11). Thus, across counties, an average of 85% of farmers supported the commercialisation of GM crops, 14% did not and 1% did not have an opinion.

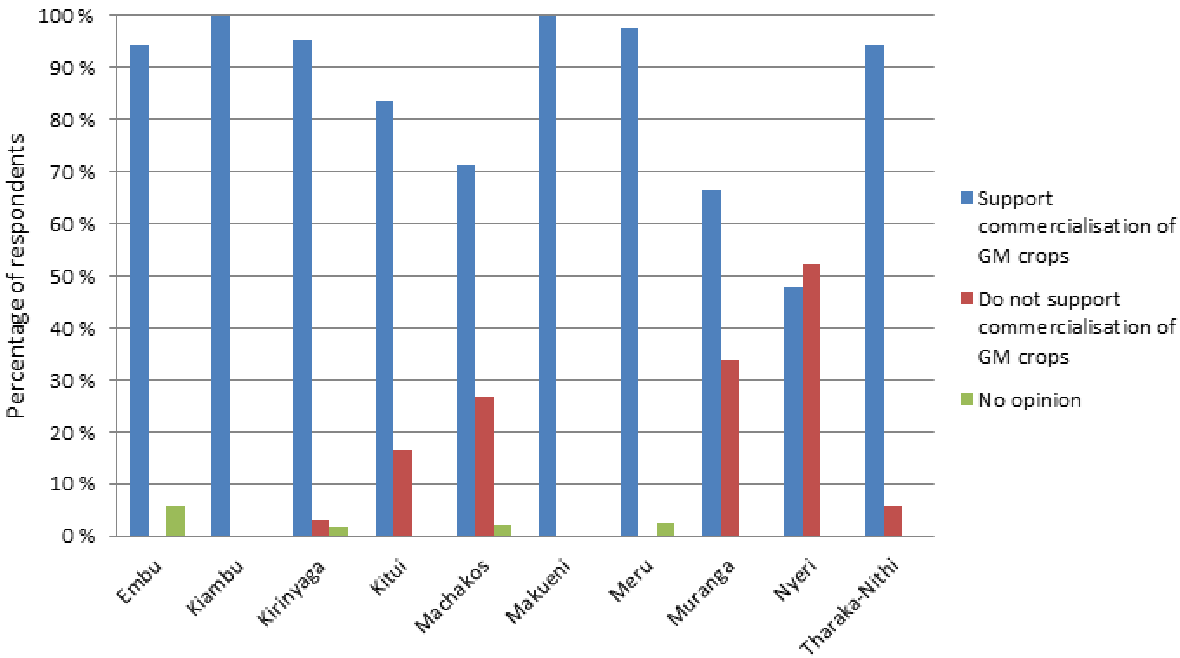


Figure 24.11. Percentage of Kenyan farmers across ten counties that supported the commercialisation of genetically modified (GM) crops (in % of respondents). There were significant differences in the level of support for commercialisation across counties ($p<0.001$). Response rate: ~100% (1122 out of 1127 participants).

The fraction of farmers that supported commercialisation was positively correlated with the fraction that had a favourable impression of the technology (Appendices 1, Table D.9.1). Contrary, there was a significant and positive correlation between the fraction of farmers that did not support the commercialisation of GM crops and the fraction of farmers that had an unfavourable impression of the technology (Appendices 1, Table D.9.1).

Concerns associated with the adoption of genetically modified (GM) crops

Generally, Kenyan farmers expressed high levels of concerns about most issues raised (Table 24.6), though there were significant differences in the level of concern across counties (Appendices 1, Appendix D.3 and D.6). Overall, the most pressing concerns were “negative environmental effects”, “negative health effects” and “low profitability and hence increased debt”. Farmers were least concerned about “religious/cultural concerns”, though the majority of farmers were “very concerned” as opposed to “not concerned”.

Table 24.6. Level of concern associated with potential negative effects of genetically modified (GM) crops among Kenyan farmers; in % and [number] of total participants [1127].					
	Not concerned	**Somewhat concerned**	**Concerned**	**Very concerned**	**No answer**
Negative environmental effects[1]	11.2 [127]	7.8 [88]	11.8 [134]	66.5 [750]	2.4 [28]
Negative health effects[2]	9.6 [109]	5.1 [58]	17.2 [194]	64.9 [732]	3.0 [34]
Low profitability and hence increased debt	12.0 [136]	6.5 [74]	12.5 [141]	63.9 [721]	4.8 [55]
Consumer reluctance to buy GM products and hence loss of income	12.9 [146]	4.1 [47]	21.2 [240]	57.7 [651]	4.0 [46]
Intellectual property rights protection for seed companies and loss of Farmers' Rights (e.g. loss of control over re-use of seeds)	11.9 [135]	14.9 [169]	13.8 [156]	55.7 [628]	2.4 [28]
Religious/cultural concerns[3]	36.7 [414]	11.1 [127]	5.7 [65]	42.1[475]	4.0 [46]

[1] Exemplified in the questionnaire as "e.g. loss of traditional varieties and genetic diversity due to GM contamination with indigenous varieties, increased use of herbicides and pesticides due to resistance development by pests and pathogens because of cross pollination between GM crops and conventional crops/weeds)".
[2] Exemplified in the questionnaire as "allergenicity/toxicity".
[3] Exemplified in the questionnaire as "e.g. sourcing genes from culturally or religiously unacceptable organisms".

Across counties, an average of 72% of farmers also expressed concerns about "having to buy good quality seeds from seed companies every season", while 27% were not concerned (note that the question was not framed in a way which explicitly referred to GM varieties) (Fig. 24.12). 100% of farmers in Embu, Kitui, Makueni and Muranga expressed such concerns, 98% in Kirinyaga, 83% in Kiambu, 67% in Machakos, 54% in Nyeri and 23% in Meru, while none of the farmers in Tharaka-Nithi had such concerns (Fig. 24.12).

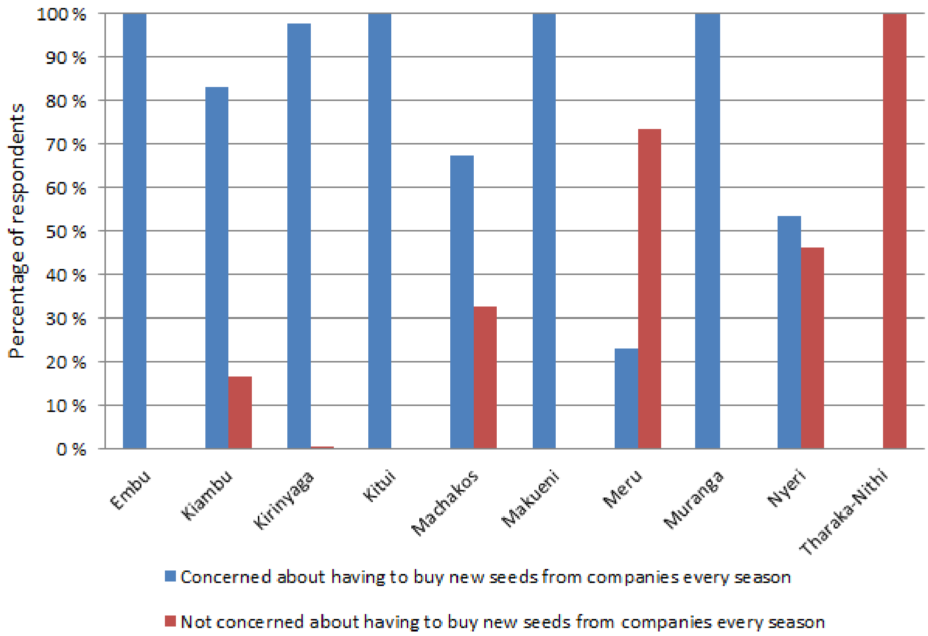


Figure 24.12. Concerns associated with seed stewardship among Kenyan farmers across ten counties (in % of respondents). There were significant differences in the level of concerns associated with seed stewardship across counties (p<0.001). Response rate: ~99% (1120 out 1127 participants).

Sources of information on genetically modified (GM) crops

Across counties, the most common source of information on GM crops was "the media" (~74%), followed by "non-governmental organisations" (NGOs) (~36%), "researchers/extension workers" (~28%), "statements by governmental officials" (~27%) and "seed/input companies" (~19%) (Table 24.7).

Table 24.7. Sources of information on genetically modified (GM) crops among Kenyan farmers divided by county; in % and [number] of total participants in each county.

	The media	Statement by governmental officials	Researchers/extension workers	Non-governmental organisation	Seed/input companies
Embu [70]	87.1 [61]	54.2 [38]	22.8 [16]	58.5 [41]	35.7 [25]
Kiambu [71]	90.1 [64]	67.6 [48]	19.7 [14]	47.8 [34]	32.3 [23]
Kirinyaga [126]	96.8 [122]	58.7 [74]	77.7 [98]	73.8 [93]	52.3 [66]
Kitui [61]	16.3 [10]	4.9 [3]	19.6 [12]	95.0 [58]	0.0 [0]
Machakos [150]	78.6 [118]	56.6 [85]	24.6 [37]	58.0 [87]	22.6 [34]
Makueni [75]	80.0 [60]	13.3 [10]	30.6 [23]	5.3 [4]	13.3 [10]
Meru [203]	68.9 [140]	0.0 [0]	0.0 [0]	15.2 [31]	12.3 [25]
Muranga [72]	97.2 [70]	26.3 [19]	2.7 [2]	29.1 [21]	15.2 [11]
Nyeri [71]	94.3 [67]	8.4 [6]	9.8 [7]	35.2 [25]	35.2 [25]
Tharaka-Nithi [228]	49.5 [113]	7.0 [16]	45.6 [104]	4.8 [11]	0.0 [0]
Total/average [1127]	~74 [845]	~27 [299]	~28 [313]	~36 [405]	~19 [219]

Note: Farmers could submit >1 source(s) of information.

Increase in the demand for genetically modified (GM) crops in response to acquisition of novel information about GM crop-adopting farmers in Burkina Faso

Farmers were told that Bt cotton-adopting farmers in Burkina Faso had experienced an average increase in yield of almost 20%, a reduction in pesticide-use by ~67%, and a 51% increase in income levels compared to conventional cotton. In response to this information, 100% of farmers in Kiambu, Makueni and Tharaka-Nithi reported of an increase in demand for biotech crops, 99% in Kirinyaga (1% reported of no increase in demand), 97% in Meru (3% did not respond; not shown in Fig. 24.13), 94% in Embu (6% did not have an opinion), 84% in Kitui (16% reported of no increase in demand), 73% in Machakos (23% reported of no increase in demand, while 3% did not have an opinion), 71% in Muranga (29% reported of no increase in demand), and 49% in Nyeri (51% reported of no increase in demand) (Fig. 24.13). Thus, an average of 90% of farmers across counties said that information about Bt cotton-adopting farmers in Burkina Faso made them want to demand GM crops themselves, 9% reported of no increase in demand, while 1% did not have an opinion (Fig. 24.13).

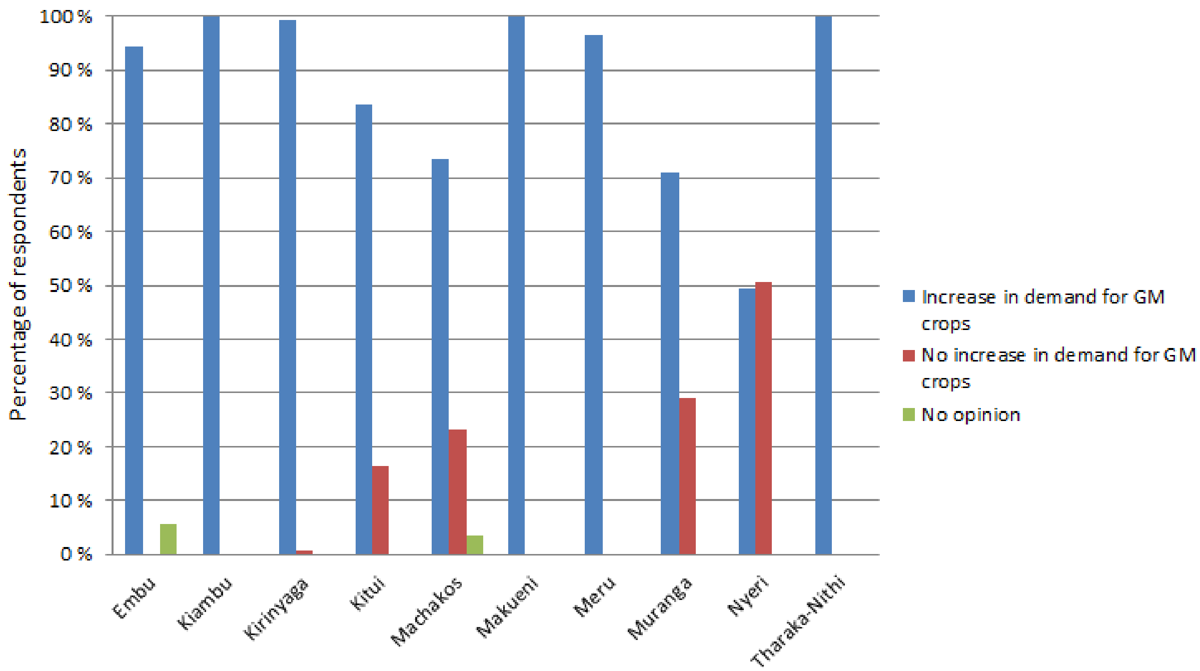


Figure 24.13. Impact of newly acquired information about positive results obtained by genetically modified (GM) crop-adopting farmers in Burkina Faso on the demand for GM crops among Kenyan farmers across ten counties (in % of respondents). There were significant differences in the level of increase in demand for GM crops across counties (p<0.001). Response rate: ~100% (1122 out of 1127 participants).

There was a significant correlation between the fraction of farmers that had a favourable impression of GM crops and the fraction that reported of an increase in demand in response to information about Bt cotton-adopting farmers in Burkina Faso, while the correlation was negative and significant between the fraction of farmers with an unfavourable impression and the fraction reporting of an increase in demand (Appendices 1, Table D.9.1).

The simulation model also found a positive and significant correlation between the fraction of farmers that reported of an increase in demand and the fraction that supported commercialisation (Appendices 1, Table D.9.1). Contrary, there was a significant and positive association between those that reported of no increase in demand and those that did not support the commercialisation of GM crops (Appendices 1, Table D.9.1).

The effect of geographical location on awareness, impressions, perceptions and acceptance of genetically modified (GM) crops

For all relationships investigated, there were significant differences in farmer awareness and responses on the basis of geographical location (i.e. counties). Please refer to Appendices 1, Table D.6 for all results.

The effect of demographic factors on awareness, impressions, perceptions and acceptance of genetically modified (GM) crops

In Kenya, education and cultural leaning were found to be significantly correlated with awareness and opinions expressed by farmers (Appendices 1, Table D.9.1).

There was a significant, negative correlation between the fraction of farmers with primary education and the fraction of aware farmers, and vice versa for the fraction of farmers with secondary education. Additionally, the fraction of farmers with primary education was negatively correlated with the fraction of farmers having a favourable impression of biotech crops, while there was a weakly significant and positive correlation between the fraction of farmers with secondary education and the fraction of farmers with a favourable impression. No significant correlations were found for the fraction of farmers with higher education (i.e. some college, Bachelor, Master and PhD).

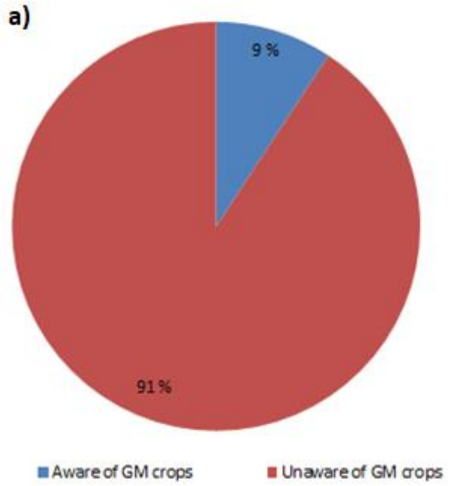
In terms of cultural leaning, there was a negative correlation between the fraction of culturally conservative farmers and the fraction having a favourable impression of GM crops, the fraction that were willingness to grow GM crops, and the fraction supporting commercialisation. The correlations between the before-mentioned opinions and the fraction of culturally liberal farmers were positive, but not significant.

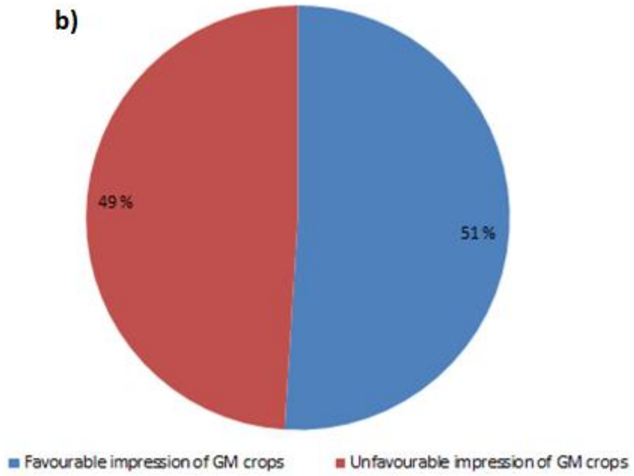
24.3.2. Results from the Ugandan farmer survey

Please refer to Appendices 1, Appendix D.5 for data at the group-level.

Awareness and impressions of genetically modified (GM) crops

An average of 91% of Ugandan farmers was unaware of GM crops, while 9% was aware (Fig. 24.14a). 51% of respondents had a favourable impression of GM crops, while 49% had an unfavourable impression (Fig. 24.14b). 43% of participants believed that farmers in their area had a favourable impression of the technology, while 28% were of the opposite opinion (29% did not know) (Fig. 24.14c).





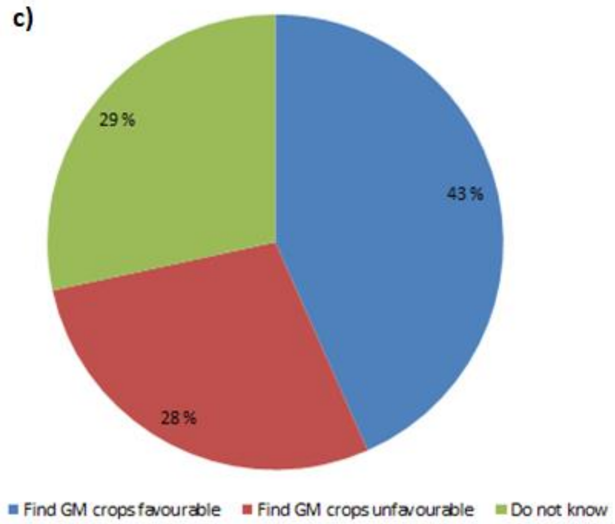


Figure 24.14. a) Level of awareness of genetically modified (GM) crops among Ugandan farmers in the districts of Wakiso, Mukono, Mpigi and Luwero (in % of respondents). Response rate: ~99% (140 out of 142 participants). **b) Impressions of GM crops among Ugandan farmers in the districts of Wakiso, Mukono, Mpigi and Luwero (in % of respondents).** Response rate: ~37% (53 out of 142 participants). Note that the low response rate was because the question was meant to presuppose awareness of GM crops. **c) Percentage of Ugandan farmers in the districts of Wakiso, Mukono, Mpigi and Luwero that believed farmers in their area had a favourable impression of GM crops (in % of respondents).** Response rate: 100% (142 out of 142 participants).

The simulation model did not find any significant correlations between the initial impression that farmers had of GM crops and the perceived attitude of farmers in their area (Appendices 1, Table D.9.2).

Willingness-to-grow (WTG), perceptions of the use of genetically modified (GM) crops to improve the quality of life of farmers, and the level of support for commercialisation

On average, 86% of farmers would grow GM crops if given the opportunity, while 14% would not (Fig. 24.15a). 76% of farmers believed that biotech crops could help improve the quality of life of Ugandan farmers, 8% did not find this to be true, while 16% did not have an opinion (Fig. 24.15b). Finally, an average of 88% of Ugandan farmers supported the commercialisation of the technology, while 10% did not (2% did not have an opinion) (Fig. 24.15c).

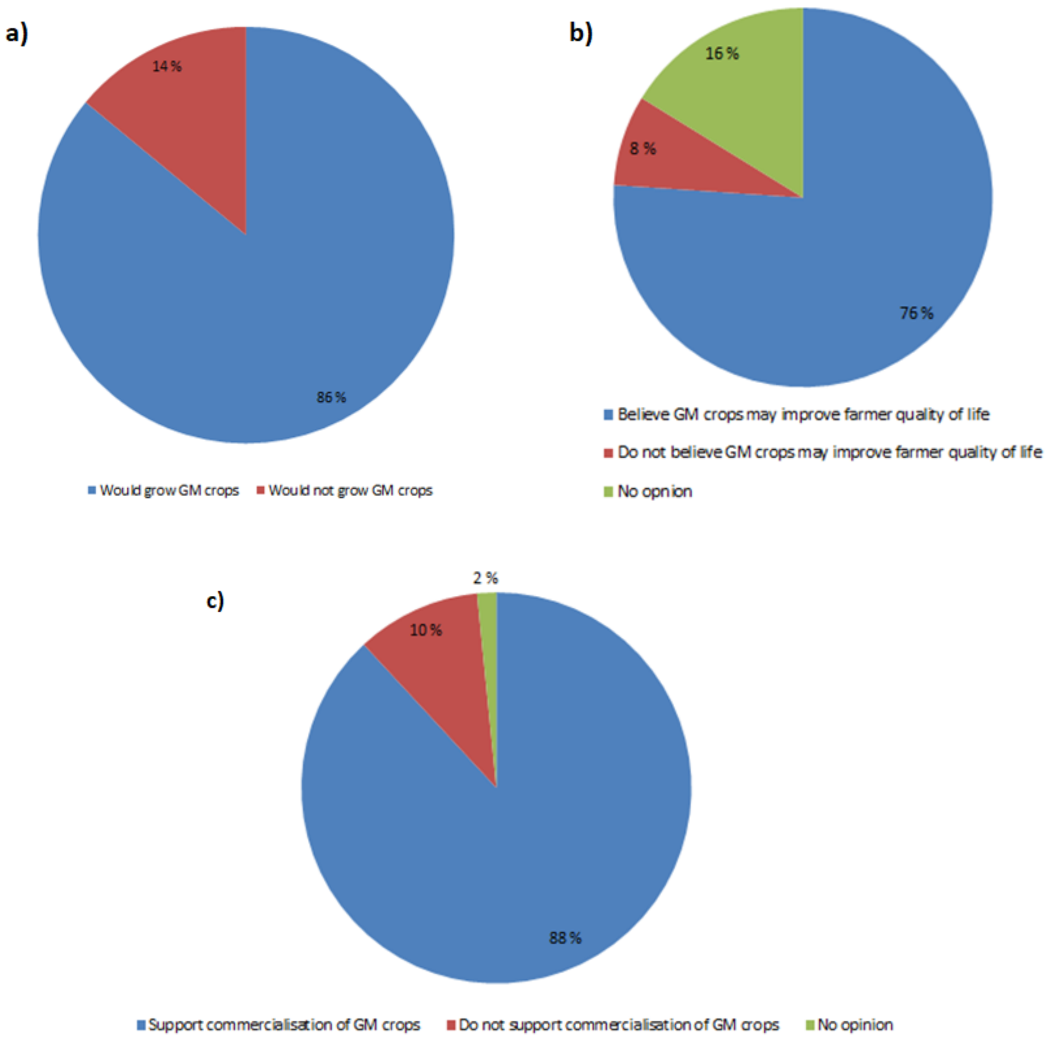


Figure 24.15. a) Willingness-to-grow (WTG) genetically modified (GM) crops among Ugandan farmers from the districts of Wakiso, Mukono, Mpigi and Luwero (in % of respondents). Response rate: ~88% (125 out of 142 participants). **b) Percentage of Ugandan farmers from the districts of Wakiso, Mukono, Mpigi and Luwero that believed GM crops could help improve the quality of life of Ugandan farmers (in % of respondents).** Response rate: 100% (142 out of 142 participants). **c) Percentage of Ugandan farmers from the districts of Wakiso, Mukono, Mpigi and Luwero that supported commercialisation of GM crops (in % of respondents).** Response rate: ~89% (126 out of 142 participants).

The simulation model did not find any significant correlations between the initial impression that farmers had of GM crops and WTG, the perception of GM crops as a way to help improve the quality of life of farmers, or the level of support for commercialisation (Appendices 1, Table D.9.2).

Concerns associated with the adoption of genetically modified (GM) crops

Ugandan farmers expressed very high levels of concerns, with the major concern being "low profitability and hence increased debt" (Table 24.8).

Table 24.8. Level of concern associated with potential negative effects of genetically modified (GM) crops among Ugandan farmers; in % and [number] of total participants [142].

	Not concerned	Somewhat concerned	Concerned	Very concerned	No answer
Low profitability and hence increased debt	0 [0]	0 [0]	12.6 [18]	76.0 [108]	11.2 [16]
Intellectual property rights protection for seed companies and loss of Farmers' Rights (e.g. loss of control over re-use of seeds)	0 [0]	0 [0]	19.7 [28]	69.0 [98]	11.2 [16]
Negative health effects [1]	0 [0]	0 [0]	21.1 [30]	67.6 [96]	11.2 [16]
Consumer reluctance to buy GM products and hence loss of income	0 [0]	0 [0]	21.1 [30]	67.6 [96]	11.2 [16]
Negative environmental effects [2]	0 [0]	7.7 [11]	21.1 [30]	59.8 [85]	11.2 [16]
Religious/cultural concerns[3]	35.2 [50]	23.2 [33]	7.7 [11]	22.5 [32]	11.2 [16]

[1] Exemplified in the questionnaire as "e.g. loss of traditional varieties and genetic diversity due to GM contamination with indigenous varieties, increased use of herbicides and pesticides due to resistance development by pests and pathogens because of cross pollination between GM crops and conventional crops/weeds).
[2] Exemplified in the questionnaire as "allergenicity/toxicity.
[3] Exemplified in the questionnaire as "e.g. sourcing genes from culturally or religiously unacceptable organisms".

Additionally, an average of 78% of farmers were worried about "having to buy good quality seeds from seed companies every season", while 22% were not concerned (Fig. 24.16).

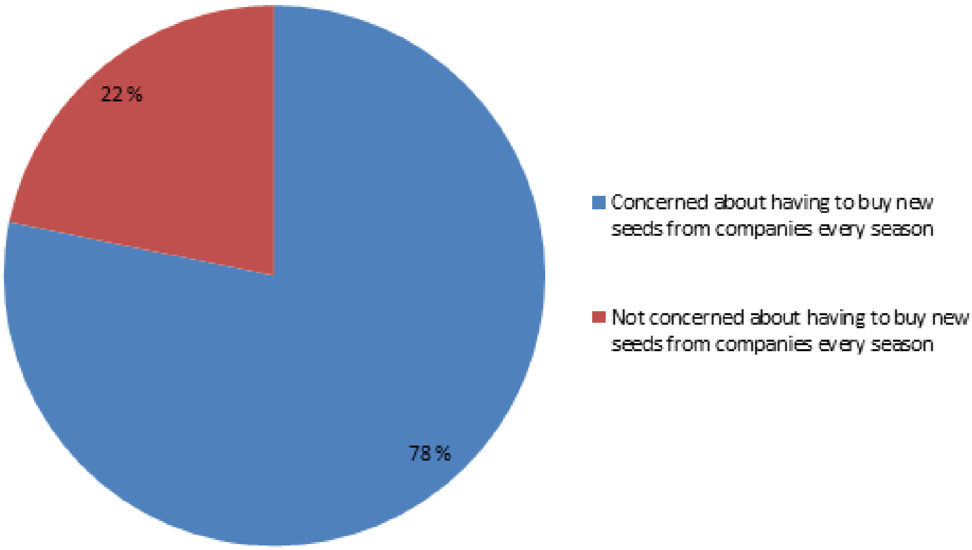


Figure 24.16. Concerns associated with seed stewardship among Ugandan farmers in the districts of Wakiso, Mukono, Mpiji and Lowelo (% of respondents). Response rate: 100% (142 out of 142 participants).

Sources of information on genetically modified (GM) crops

The most common source of information on GM crops was "the media" (46%), followed by "statements by governmental officials" (13%), "researchers/extension workers" (4%), "non-governmental organisations" (NGOs) (3%) and "seed/input companies" (3%) (Table 24.9).

Table 24.9. Sources of information on genetically modified (GM) crops among Ugandan farmers in the districts Wakiso, Mukono, Mpiji and Lowelo (divided by farmer group); in % and [number] of participants aware of GM crops.

	The media	Statements by governmental officials	Researchers/extension workers	Non-governmental organisation	Seed/input companies
Group 1	100 [1]	100 [1]	0 [0]	0 [0]	0 [0]
Group 2	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
Group 3	100 [4]	0 [0]	0 [0]	0 [0]	0 [0]
Group 4	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
Group 5	100 [1]	0 [0]	0 [0]	0 [0]	0 [0]
Group 6	100 [2]	100 [2]	0 [0]	0 [0]	0 [0]
Group 7	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
Group 8	100 [3]	100 [3]	100 [3]	100 [3]	100 [3]
Group 9	100 [1]	0 [0]	0 [0]	0 [0]	100 [1]
Group 10	0 [0]	0 [0]	100 [1]	0 [0]	0 [0]
Total	~41 [12]	~21 [6]	~14 [4]	~10 [3]	~14 [4]
Note: Farmers could submit >1 source(s) of information.					

Increase in the demand for genetically modified (GM) crops in response to acquisition of novel information about GM crop-adopting farmers in Burkina Faso

Farmers were told that Bt cotton-adopting farmers in Burkina Faso had experienced an average increase in yield of almost 20%, a reduction in pesticide-use by ~67%, and a 51% increase in income levels compared to conventional cotton. An average of 86% of farmers said that information led to an increase in demand for biotech crops, 10% reported of no increase in demand, while 4% did not have an opinion (Fig. 24.17).

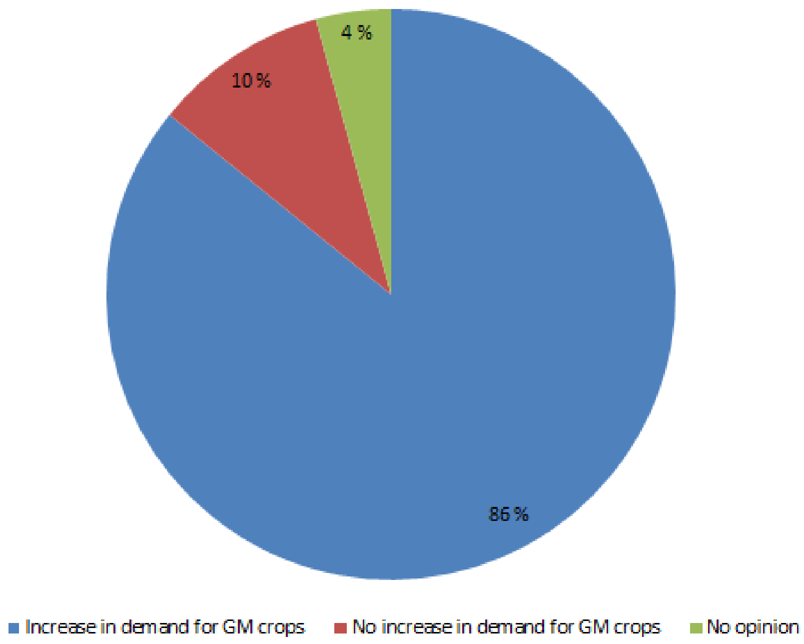


Figure 24.17. Impact of newly acquired information about positive results obtained by genetically modified (GM) crop-adopting farmers in Burkina Faso on the demand for GM crops among Ugandan farmers from the districts of Wakiso, Mukono, Mpigi and Luwero (in % of respondents). Response rate: ~99% (141 out of 142 participants).

The simulation model did not find any statistically significant correlations between the impression of GM crops and the level of increase in demand, or between the level of demand and the support for commercialisation (Appendices 1, Table D.9.2).

The effect of demographic factors on awareness, attitudes and perceptions of genetically modified (GM) crops

In Uganda, sex, education, marital status and cultural leaning were found to be significantly correlated with awareness and opinions expressed by farmers (Appendices 1, Table D.9.2).

There were significant and negative correlations between the fraction of farmers aware of GM crops and the fraction of female farmers and farmers with primary education, while the correlations were positive for the fraction of male farmers and farmers with secondary education. Additionally, there was a negative correlation between the fraction that supported commercialisation and the fraction of male farmers and farmers with higher education (i.e. some college, Bachelor, Master and PhD), while the correlation between the fraction of female farmers and the fraction supporting commercialisation was positive and significant.

A significant, negative correlation was found between the fraction of married farmers and the fraction that supported commercialisation of GM crops, while the relationship between the fraction of single farmers and support for commercialisation was also negative, but not significant. Finally, a negative and weakly significant correlation was evident between the fraction of culturally moderate farmers and the fraction having a favourable impression of GM crop for logit transformed data, while no significant correlations were found for culturally liberal or conservative farmers.

24.3.3. Results from the Tanzanian farmer survey

Results from the investigation of geographical effects on farmer responses are summarised towards the end of the subchapter.

Awareness and impressions of genetically modified (GM) crops

In Karatu, 10% of farmers were aware of GM crops (90% were unaware), while 16% were aware in Babati (84% were unaware) (Fig. 24.18). Thus, an average of 13% of farmers across districts was aware of GM crops, while 87% was unaware.

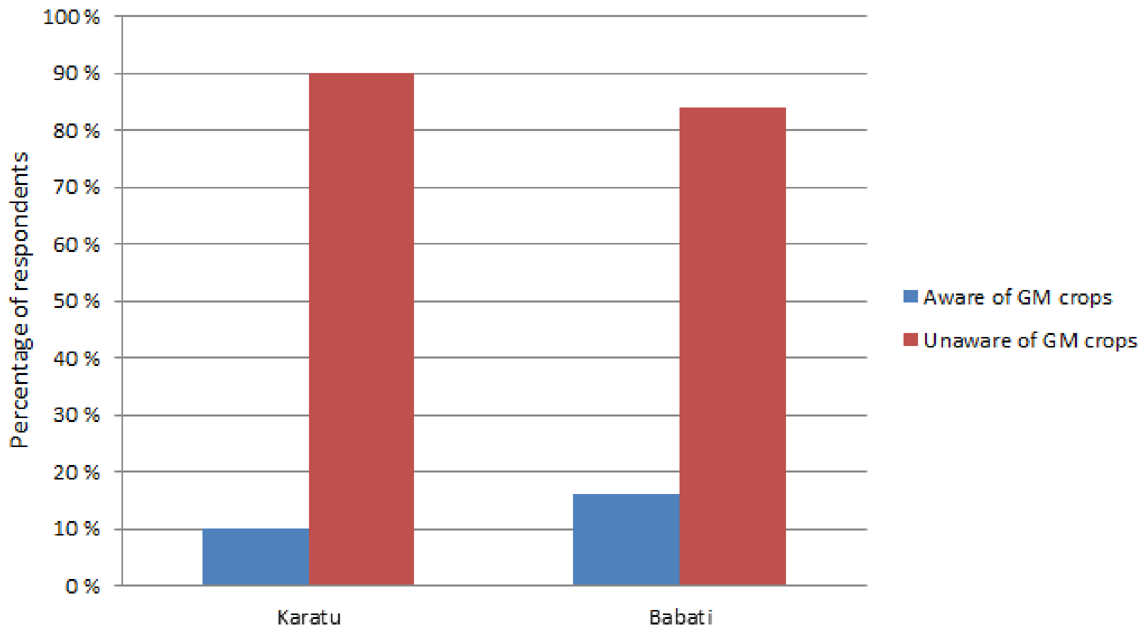


Figure 24.18. Level of awareness of genetically modified (GM) crops among Tanzanian farmers in the districts of Karatu and Babati (in % of respondents). There were significant differences in the level of awareness across districts ($p<0.05$). Response rate: ~97% (781 out of 805 participants).

67% and 83% of respondents had a favourable impression of GM crops in Karatu and Babati, respectively (33% and 17% had an unfavourable impression, respectively) (Fig. 24.19). Thus, on average, 75% of farmers across districts had a favourable impression of GM crops, while 25% had an unfavourable impression.

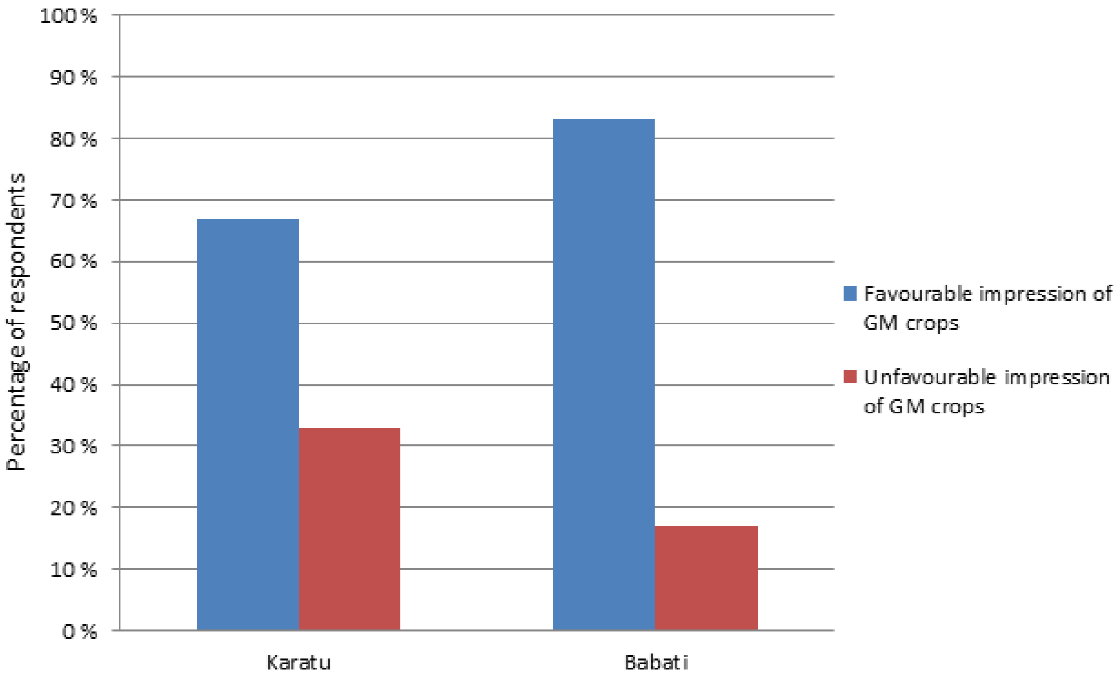


Figure 24.19. Impressions of genetically modified (GM) crops among Tanzanian farmers in the districts of Karatu and Babati (in % of respondents). There were no significant (NS) differences in farmer impressions across districts ($p>0.05$). Response rate: ~11% (88 out of 805 participants). Note that the low response rate was because the question was meant to presuppose awareness of GM crops.

In Karatu, 62% of respondents believed that farmers in their area had a favourable impression of GM crops, 22% were of the opposite opinion, while 16% did not know (Fig. 24.20). In Babati, 85% of respondents believed that farmers in their area had a favourable impression of GM crops, 9% believed the opposite to be true, while 6% did not have an opinion (Fig. 24.20). Thus, an average of 73.5% of farmers across districts perceived farmers in their area as having a favourable attitude towards biotech crops, 15.5% were of the opposite impression and 11% did not have an opinion.

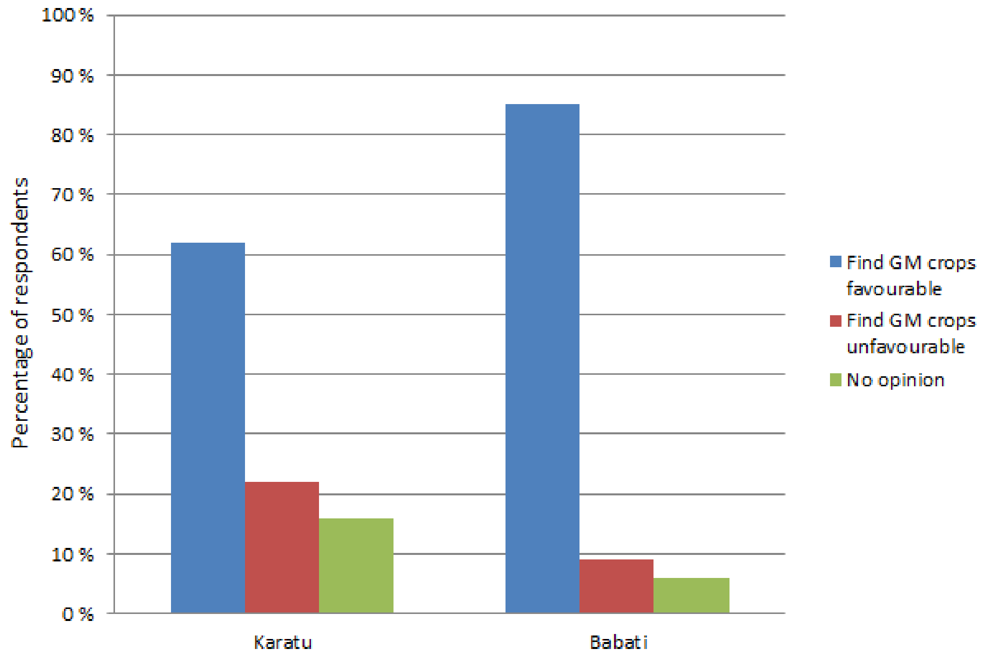


Figure 24.20. Percentage of Tanzanian farmers in the districts of Karatu and Babati that believed farmers in their area had a favourable impression of genetically modified (GM) crops (in % of respondents). There were significant differences in farmer opinions across districts (p<0.001). Response rate: ~100% (803 out of 805 participants).

The simulation model did not find any significant correlations between the initial impression that farmers had of GM crops and the perceived attitude of farmers in their area (Appendices 1, Table D.9.3).

Willingness-to-grow (WTG), perceptions of the use of genetically modified (GM) crops to improve the quality of life of farmers, and the level of support for commercialisation.

In Karatu, 98% of farmers would grow GM crops if given the opportunity (2% would not), while 100% of farmers in Babati would grow (Fig. 24.21). Thus, across districts, an average of 99% of Tanzanian farmers would grow biotech crops, while 1% would not.

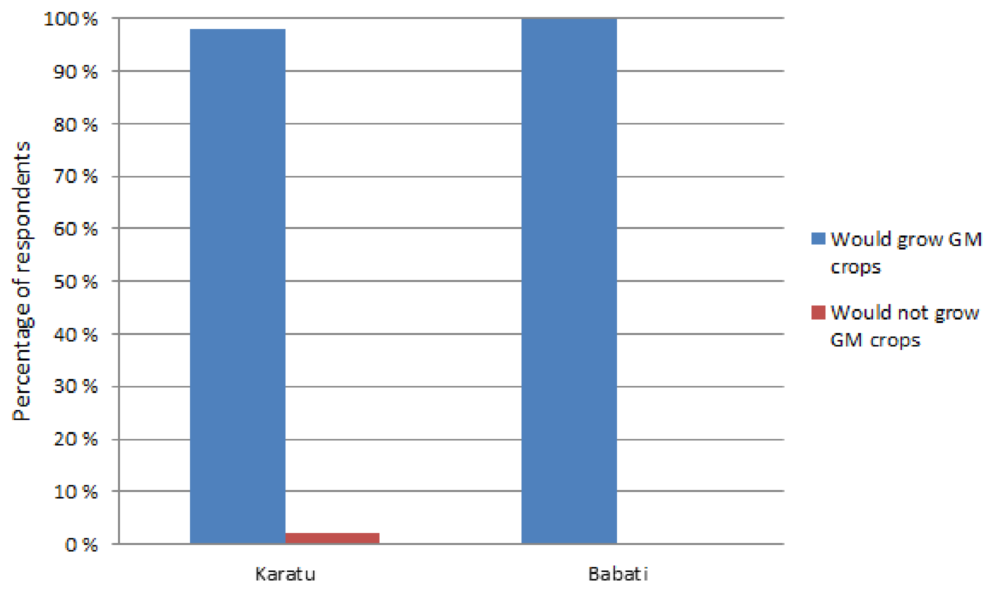


Figure 24.21. Willingness-to-grow (WTG) genetically modified (GM) crops among Tanzanian farmers from the districts of Karatu and Babati (in % of respondents). There were significant differences in WTG across districts (p<0.01). Response rate: ~99% (800 out of 805 participants).

In Babati, 98% of farmers believed that GM crops could help improve the quality of life of Tanzanian farmers, while 2% did not have an opinion (Fig. 24.22). In Karatu, 84% found this to be true, 1% did not and 11% did not have an opinion (4% did not respond; not shown in Fig. 24.22) (Fig. 24.22). Thus, an average of 91% of farmers across districts believed that GM crops could help improve the quality of life of Tanzanian farmers, 0.5% was of the opposite opinion and 6.5% did not know (2 % did not respond).

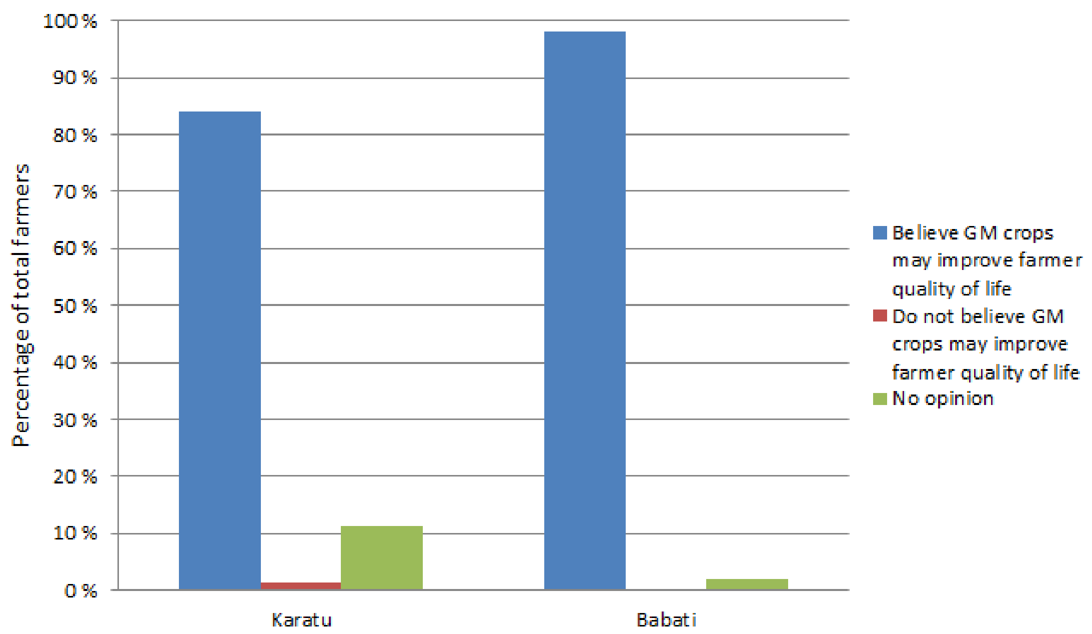


Figure 24.22. Percentage of Tanzanian farmers from the districts of Karatu and Babati that believed genetically modified (GM) crops could help improve the quality of life of Tanzanian farmers (in % of respondents). There were significant differences in farmer perceptions across districts (p<0.01). Response rate: ~99% (795 out of 805 participants).

In Babati, 97% of farmers supported the commercialisation of GM crops, 1% did not support commercialisation, while 2% did not have an opinion (Fig. 24.23). In Karatu, 95% supported commercialisation, while 5% did not have an opinion (Fig. 24.23). Thus, across districts, an average of 96% of farmers supported the commercialisation of GM crops, 0.5% did not support commercialisation, while 3.5% had no opinion.

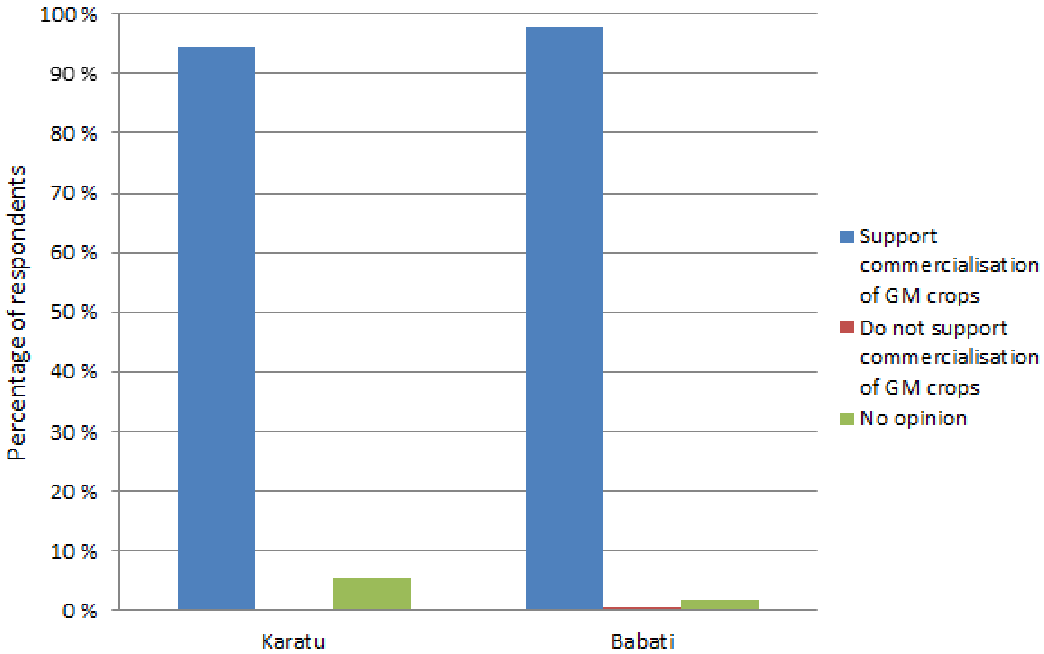


Figure 24.23. Percentage of Tanzanian farmers from the districts of Babati and Karatu that supported the commercialisation of genetically modified (GM) crops (in % of respondents). There were significant differences in the level of support for commercialisation across districts ($p<0.01$). Response rate: ~99% (796 out of 805 participants).

Note that it was decided to forego the analyses of any potential relationship between farmer impressions of GM crops and WTG, perceptions of GM crops as a way to improve farmer quality of life and the level of support for commercialisation, as the variation upon which to estimate the correlation was too small (i.e. only two, three and five respondents did not want to grow GM crops, did not think GM crops could help improve farmer quality of life, and did not support commercialisation, respectively).

Concerns associated with the adoption of genetically modified (GM) crops

Tanzanian farmers expressed overall low levels of concerns, whereby the majority of farmers were "not concerned" (Table 24.10). The issue perceived as most concerning was "negative health effects", with the least being "religious/cultural concerns". Still, there were significant differences in the level of concern on the basis of geographical location (Appendices 1, Appendix D.4 and D.7).

Table 24.10. Level of concern associated with potential negative effects of genetically modified (GM) crops among Tanzanian farmers; in % and [number] of total participants [805].

	Not concerned	Somewhat concerned	Concerned	Very concerned	No answer
Negative health effects [1]	58.0 [467]	30.8 [248]	7.8 [63]	2.4 [20]	0.8 [7]
Intellectual property rights protection for seed companies and loss of Farmers' Rights (e.g. loss of control over re-use of seeds)	56.1 [452]*	34.6 [279]	6.5 [53]	2.9 [24]	-
Low profitability and hence increased debt	41.7 [336]	46.7 [376]	8.6 [70]	1.4 [12]	1.3 [11]
Negative environmental effects [2]	66.8 [538]**	26.8 [216]	6.4 [52]	0.3 [3]	-
Consumer reluctance to buy GM products and hence loss of income	44.5 [359]	49.1 [396]	3.7 [30]	0.3 [3]	2.1 [17]
Religious/cultural concerns [3]	87.7 [707]	9.8 [79]	1.1 [9]	0.3 [3]	0.8 [7]

[1]Exemplified in the questionnaire as "allergenicity/toxicity.
[2]Exemplified in the questionnaire as "e.g. loss of traditional varieties and genetic diversity due to GM contamination with indigenous varieties, increased use of herbicides and pesticides due to resistance development by pests and pathogens because of cross pollination between GM crops and conventional crops/weeds).
[3]Exemplified in the questionnaire as "e.g. sourcing genes from culturally or religiously unacceptable organisms".
* Three more respondents than total number of farmers.
** Four more respondents than total number of farmers.

81% of farmers in Babati were worried about "having to buy good quality seeds from seed companies every season", while 18% were not concerned (1% did not reply; not shown in Fig. 24.24). The same applied to 77% of farmers in Karatu, while 23% were not concerned (Fig. 24.24). Thus, an average of 79% of farmers across districts were concerned about having to buy new, good quality seeds every season, while 20.5% were not concerned (0.5% did not respond).

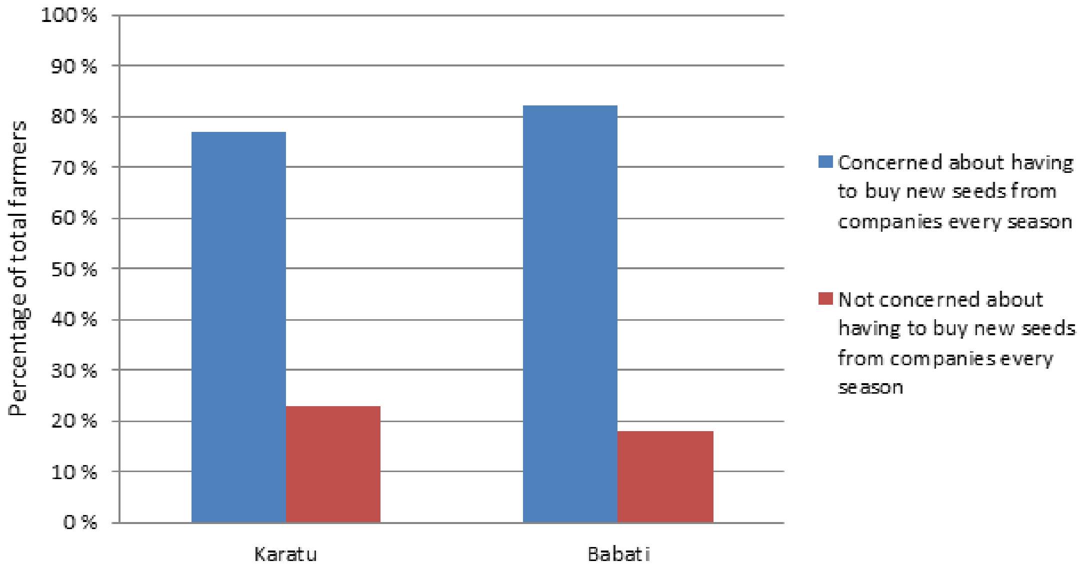


Figure 24.24. Concerns related to seed stewardship among Tanzanian farmers from the districts of Karatu and Babati (in % of respondents). There were NS differences in the level of concerns associated with seed stewardship across districts ($p>0.05$). Response rate: ~99% (800 out of 805 participants).

Sources of information on genetically modified (GM) crops

The most common source of information on biotech crops among Tanzanian farmers were "non-governmental organisations" (7%), followed by "the media" (6%), "researchers/extension workers" (5%) and "seed/input companies" (3%) (Table 24.11). "Statements by governmental officials", "researchers/extension workers" and "seed/input companies" were most prominent in Karatu, while "the media" was a considerable more important channel of information in Babati (Table 24.11)

Table 24.11. Sources of information on genetically modified (GM) crops among Tanzanian farmers divided by district; in % and [number] of total participants [805].

	The media	Statements by governmental officials	Researchers/extension workers	Non-governmental organisation	Seed/input companies
Babati [574]	7.6 [44]	0.5 [3]	2.7 [16]	4.8 [28]	0.3 [2]
Karatu [231]	0.8 [2]	11.2 [26]	10.8 [25]	11.6 [27]	10.8 [25]
Total [805]	~6 [46]	~4 [29]	~5 [41]	~7 [55]	~3 [27]

Note: Farmers could submit >1 source(s) of information.

Increase in the demand for genetically modified (GM) crops in response to acquisition of novel information about GM crop-adopting farmers in Burkina Faso

Farmers were told that Bt cotton-adopting farmers in Burkina Faso had experienced an average increase in yield of almost 20%, a reduction in pesticide-use by ~67%, and a 51% increase in income levels compared to conventional cotton. In response to this information, 81% of farmers in Babati reported of an increase in demand for GM crops by 98% (2% did not have an opinion), while 95% of farmers in Karatu reported of an increase in demand (5% did not have an opinion) (Fig. 24.25). Thus, an average of 96.5% of farmers across districts said that this information led to an increase in demand for biotech crops, while 3.5% did not have an opinion on the matter.

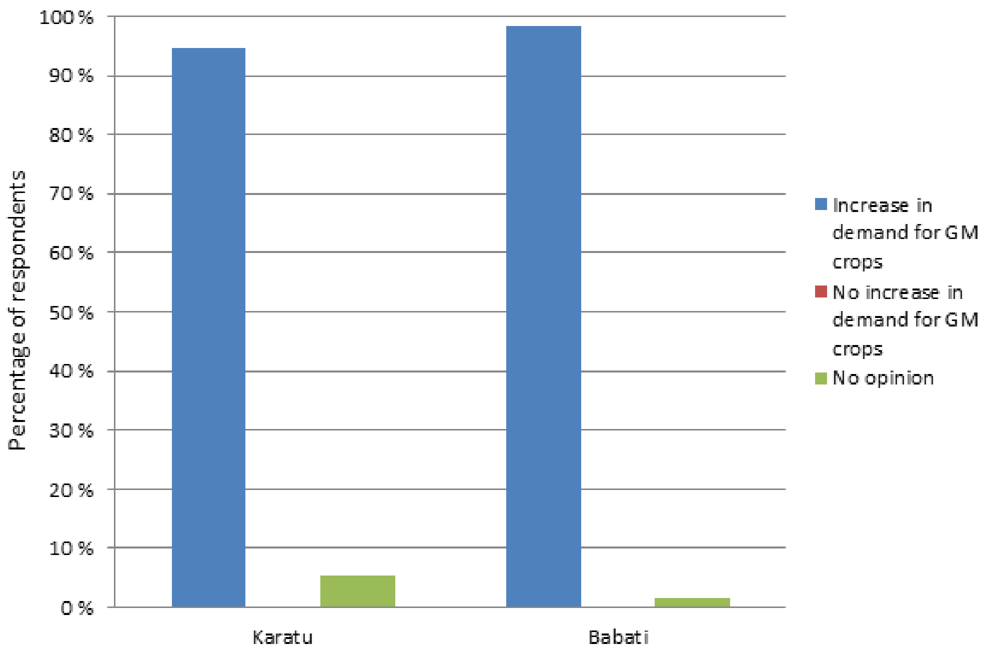


Figure 24.25. Impact of newly acquired information about positive results obtained by genetically modified (GM) crop-adopting farmers in Burkina Faso on the demand for GM crops among Tanzanian farmers from the districts of Karatu and Babati (in % of respondents). There were significant differences in the level of increase in demand for GM crops across districts ($p<0.01$). Response rate: ~99% (796 out of 805 participants).

As none of the farmers reported of no increase in demand in response to information about Bt crop-adopting farmers in Burkina Faso, and only two farmers were found not to support commercialisation, any correlation between level of increase in demand and the level of support for commercialisation was not investigated.

The effect of geographical location on awareness, impression, perception and acceptance of genetically modified (GM) crops

For most relationships investigated, the simulation model found strongly significant differences in farmer awareness and responses on the basis of geographical location (i.e. districts) (Appendices 1, Table D.7). However, no significant differences were found in the case of (i) farmer impressions of GM crops, (ii) the level of concern associated with having to buy new seeds from seed companies every season, and (iii) the degree of challenge associated with certain agricultural constraints (for the latter, see Chapter 2, section 2.6).

The effect of demographic factors on awareness, attitudes and perceptions of genetically modified (GM) crops

The investigation of any potential relationships between demographics and WTG and support for commercialisation was not carried out due low levels of variation. In terms of awareness and impressions of GM crops, significant correlations were found for sex and education (Appendices 1, Table D.9.3).

There was a weakly significant and positive correlation between the fraction of male farmers and the fraction of aware farmers, while no significant relationship was found for the fraction of female farmers. Additionally, there was a positive and significant correlation between the fraction of aware farmers and the fraction of farmers with higher education (i.e. some college, Bachelor, Master and PhD) for logit transformed data. Though non-significant, the correlation for the fraction of farmers with primary education was positive, while it was negative for the fraction of farmers with secondary education.

24.3.4. The effect of nationality on farmer responses

There were significant differences in farmer responses on the basis of nationality (Appendices 1, Table D.8), with the exception of (i) the level of awareness among Ugandan and Tanzanian farmers, (ii) willingness-to-grow among Kenyan and Ugandan farmers, and (iii) support for commercialisation among Kenyan and Ugandan farmers. Additionally, there were non-significant differences in the perceived degree of challenge associated with “poor infrastructure for market access (roads, communication)” and “spending too much time in the field” (i.e. agriculturalconstraints; Chapter 2, section 2.6) among Kenyan and Ugandan farmers.

24.4. Discussion: Farmer surveys

24.4.1. Awareness, impressions, perceptions and acceptance of genetically modified (GM) crops among Kenyan, Ugandan and Tanzanian farmers

Level of awareness of genetically modified (GM) crops

There were significant differences in farmer responses on the basis of nationality (Appendices 1, Table D.8). Kenyan farmers exhibited the highest level of awareness (~77%), followed by Tanzanian (~13%) and Ugandan (~9%) farmers. Given the country's relatively long history with agricultural biotechnology, it would be natural to assume that Kenyan farmers have had a higher exposure to the GMO debate compared to Ugandan and Tanzanian farmers. However, Uganda also boasts a relatively long history of practical experience and involvement in the topic, but Ugandan farmers exhibited the lowest level of awareness. This may indicate that the GMO debate has not gained much public advocacy, and further contradicts the hypothesis that countries with a longer practical history dealing with the technology exhibit a higher level of awareness compared to those with a shorter history (e.g. Tanzania). However, in this respect, it is important to consider the relatively small sample size obtained in Uganda, which reduces its representativeness and comparability.

In Kenya, there were significant differences in the level of awareness across counties. For instance, all farmers from Muranga County were aware of GM crops, while as few as 30% were aware in Tharaka Nithi (Fig 24.6). Such differences may reflect demographic factors (e.g. educational level and sex), the presence of activities by researchers, extension workers, NGOs, seed/input companies and so forth, as well as other geographical, infrastructural and agro-ecological characteristics. Still, the average level of awareness of GM crops among Kenyan farmers was higher than what has been reported previously (e.g. Kimenju *et al*., 2011; Njoka *et al*., 2011), which could be explained by the fact that these studies were conducted at a point in which the debate on GMOs had not gained as much attention. Additionally, the high level of awareness of the present study could reflect the proximity of the survey sites to Nairobi, whereas e.g. Njoka *et al*. (2011) investigated the level of awareness across all eight Kenyan provinces. Furthermore, the non-random and non-representative sampling may have been an influential factor (Chapter 25, section 25.1.5). For instance, it could be that the surveyed farmer groups had prior knowledge of GMOs as a result of interactions with extension workers and contact farmers that had connections to ICOSEED.

The level of awareness of GM crops among Tanzanian farmers was higher than what has been reported by Mneney (2003), Lewis *et al*. (2010) and the United Republic of Tanzania (2012), but lower than in the recently conducted study by Mnaranara *et al*. (2017). The higher level of awareness of the latter study could reflect differences in sampling size (i.e. N=129 compared to N=805 of the present study) and sites (the survey conducted by Mnaranara *et al*. included the towns of Shinyanga and Sinigida, which are located further north and in the central regions of Tanzania, respectively). That being said, the choice of survey sites of the present study was based on the idea that some level of awareness would exist here. This assumption was not based on any published data, but on a set of considerations: (i) some training associated with GMOs had been conducted in Arusha; (ii) the headquarter of the East African Community (EAC) is located in the region; (iii) it is close to Kenya; and (iv) a lot of tourists visit the area (Nyalusi, pers. comm.). There were in fact significant differences in the level of awareness across districts, whereby the highest level of awareness was recorded in Karatu which is located in the Arusha region (Fig. 24.18).

However, it should be noted that the study conducted by the United Republic of Tanzania (2012) found that respondents from the central and especially the northern zones – which includes sites relatively close to the areas surveyed by both Mnaranara *et al*. (2017) and the present study – were less well-informed about GMOs than respondents from Eastern zones. If this still holds true five years following the study, it might indicate that farmers of the Eastern zone exhibit a higher level of awareness than what is reported in the survey by Mnaranara *et al*. (2017) and in the present study.

Whether the level of awareness recorded among Ugandan farmers represents an increase or decrease is not possible to determine due to the lack of previously conducted awareness studies. Still, as already touched upon, Ugandan farmers were the least aware among all farmers surveyed. Furthermore, seeing as the districts surround the capital of Kampala – where one could assume that farmers would have easier access and higher exposure to information on GM crops than for more remote areas – one could imagine that similar or even lower levels of awareness exists in more rural districts (though little is known about the level of exposure to agricultural biotechnology among farmers in other districts, for instance due to presence of research activities, extension services and higher learning institutions). The low level of awareness substantiates the argument made by certain stakeholders, namely that public awareness is an important consideration – and perhaps an obstacle – in terms of the passage of the Ugandan Biotechnology and Biosafety Bill into law (Chapter 7, section 7.3.2.2).

Impressions, perceptions and acceptance of genetically modified (GM) crops

There were significant differences in the level of favourable impressions, perceptions of whether GM crops could help improve the quality of life of farmers, WTG and the support for commercialisation on the basis of geographical location within and between study countries (Appendices 1, Table D.6-D.8).

The majority of Kenyan (~77%) and Tanzanian farmers (~75%) expressed favourable impressions of biotech crops, while only little over half of Ugandan farmers (~51%) had a positive attitude towards the technology. Still, there were significant differences in the level of favourable impressions across districts in Kenya (Appendices 1, Table D.6). For instance, 96% of farmers in Embu had favourable impressions, while less than half (41%) of farmers in Machakos expressed similar attitudes (Fig. 24.7). In Tanzania on the other hand, there were no significant differences in farmer impressions of GM crops across districts (Appendices 1, Table D.7). Thus, farmers appeared to share a common opinion of the technology regardless of geographical region (Fig. 24.19). Out of the three study countries, Tanzanian farmers – particularly those from Babati (Appendices 1, Table D.7; Fig. 6.21-6.23) – expressed the highest levels of WTG (~99%) and support for commercialisation (~96%), and ~91% of farmers believed that GM crops could help improve the quality of life of farmers. There were no significant difference in WTG and support for commercialisation among Kenyan and Ugandan farmers (i.e. ~81% and ~86% were willing to grow, while ~85% and ~88% supported the commercialisation of GM crops, respectively) (Appendices 1, Table D.8). However, there were significant differences in terms of the perception of GM crops as a way of improving the quality of life of farmers, whereby ~76% of Ugandans and ~81% of Kenyans found this to be true (Appendices 1, Table D.8). Additionally, Kenyan farmers expressed significantly different opinions and level of acceptance across counties (Appendices 1, Table D.6). For instance, 99% of farmers would grow GM crops in Kirinyaga compared to 58% in Nyeri (Fig. 24.9), while 100% of farmers in Makueni supported commercialisation, while the level of support was 48% in Nyeri (Fig. 24.11)

Still, overall, the large majority of farmers within and across study countries exhibited highly positive perceptions and acceptance of GM crops. However, the above-mentioned findings somewhat contradicts the hypothesis that a longer history of experience translates into higher level of positivity towards the technology. Possible causative factors explaining such findings – including risk perception (section 24.4.22), source of information on biotech crops (section 24.4.3), the impact of basic and novel knowledge (section 24.4.4), and demographic factors (section 24.4.5) – will be explored in later sections.

Possible bias based on general impression of genetically modified (GM) crops

Finally, it should be noted that – perhaps rather unsurprisingly – the opinions expressed by Kenyan farmers appeared to be somewhat biased on the basis of the farmers' initial impression of the technology; there were significant correlations between farmer impressions and the perceived attitude of farmers in the area, whether farmers believed GM crops could help improve the quality of life of farmers, and the level of acceptance of the technology (i.e. WTG and support for commercialisation) (Appendices 1, Table D.9.1). For instance, farmers in Nyeri and Machakos – two counties with low levels of positive impressions (Fig. 24.7) – perceived neighbouring farmers as having the least favourable attitudes towards GM crops (Fig. 24.8), while farmers from Embu and Kitui – two of the counties with the highest level of favourable impressions (Fig. 24.7) –perceived farmers in their area as having the most favourable attitudes towards the technology (Fig. 24.8). Additionally, the least amount of support for commercialisation was recorded in Muranga and Nyeri (Fig. 24.11), both of which were among the counties with the lowest levels of positive impressions (Fig. 24.7). One could argue that such findings reduce the confidence of, for instance, assessing the true attitudes of neighbouring farmers.

That being said, there did not always appear to be a direct relationship. For instance, a large majority of farmers in Kiambu had a favourable impression of biotech crops (Fig. 24.7), while only little over half believed that such an attitude also applied to farmers in their area (Fig. 24.8). Furthermore, farmers in Machakos displayed a relatively high level of support for commercialisation (Fig. 24.11). Additionally, the highest level of support for commercialisation was found among farmers in the counties Kiambu, Makueni and Meru (Fig. 24.11), which – with the exception of Meru – were not counties in which the highest levels of favourable impression had initially been recorded (Fig. 24.7).

Similar findings were not evident among Ugandan and Tanzanian farmers, which could be explained by the fact that the level of awareness and response rate for the question on farmer impressions of GM crops was very low (compared to questions concerning the acceptance of the technology), which challenges the ability of investigating such relationships.

24.4.2. Risk perception and its influence on acceptance of genetically modified (GM) crops

Perceived risks and benefits – and the dynamic relationship between the two – play an important role in determining attitudes and acceptance of biotech crops and products thereof (e.g. Bredahl *et al*., 1998; Frewer *et al*., 1998; Costa-Font *et al*., 2008; Frewer *et al.,* 2013). Differences in the level and types of concerns may reflect a variety of factors, including knowledge of basic biology and agricultural biotechnology (Bredahl *et al*., 1998); the type of information farmers and consumers have been exposed to (which could reflect the type of information channel; see section 24.4.3 below) (e.g. Curtis *et al*., 2004); trust bestowed on governments, regulators, researchers and biotech companies (e.g. Curtis *et al*., 2004); demographic factors (see section 24.4.5); and different agro-ecological, socio-economic and socio-political conditions (e.g. whether farmers perceive the agricultural policies in their country as adequate in terms of protecting Farmers' Rights).

Previously conducted perception studies have found that East African stakeholders, including consumers and farmers, express concerns about potential negative impacts of GM crops on the environment, including effects on biodiversity, local varieties, non-target insects and outbreak of new plant diseases (Kimenju & De Groote, 2008; Bett *et al*., 2010; Kikulwe *et al*., 2011; Ainembabazi *et al*., 2015); health effects and animal welfare (Bett *et al*., 2010; Kagai, 2011; Kimenju & De Groote, 2008; Kushwaha *et al.,* 2008; Kikulwe *et al*., 2011; Ainembabazi *et al*., 2015); impact on local and transboundary markets (Kagai, 2011); and ethical and equity concerns (Kimenju & De Groote, 2008).

There were significant differences in the level of concern across study countries (Appendices 1, Appendix D.8). Still, consistent with above-mentioned studies, both Kenyan and Ugandan farmers expressed high levels of concerns about potential environmental and health effects, as well as "low profitability and hence increased debt" (Table 24.6 and Table 24.8, respectively). Additionally, Ugandan farmers were particularly worried about "intellectual property rights protection for seed companies and loss of Farmers' Rights" and "consumer reluctance to buy GM products and hence loss of income" (Table 24.8). Thus, it appeared as if Ugandans expressed the highest level of concerns related to socio-economics issues and consumer preferences and acceptance. Interestingly, the additional comments made by the data collection team during the Ugandan survey made witness of a lack of trust in research stations, governments and suppliers. For instance, one group said that they had previously purchased poor varieties that they had been told were high-yielding, but that had turned out to last only a single season, as well as introducing pest and diseases to the soil. Another group had been provided with hybrid bananas and cassava which were tasteless and bitter, respectively (which further underlines the importance of taking culinary preferences into consideration when developing improved varieties). Others argued that the government did not listen to the opinions of farmers, and that they did not trust the capability of the government in assuring the safety of GMOs. They further raised concerns that corruption might hinder the delivery of potentially advantageous biotech crops.

Tanzanian farmers on the other hand, expressed overall low levels of concerns (Table 24.10). This finding is not consistent with the study by Mnaranara *et al*. (2017), but could tally well with findings by Lewis *et al*. (2010) whereby farmers knew little about the potential risks associated with GM crops. Thus, the low level of concerns could be due to lack of awareness and exposure to stories which might otherwise have contributed to controversies and misgivings.

However, based on this assumption, one would have expected Ugandan farmers – who were the least aware – to express the lowest level of concerns. Still, as apparent above, the Ugandan farmers had been exposed several unfortunate experiences using improved varieties in the past, which is likely to have made an impact on their risk perception of GM crops. In this respect, it should be noted that certain farmers – regardless of nationality – appeared to mistake GM crops for hybrids or growth hormones used in poultry (data collection team, pers. comm.). Such misconceptions were also noted during the survey by the United Republic of Tanzania (2012), whereby some of the participants confused GMOs with broiler chickens, tissue culture, improved varieties, etc.).

Furthermore, simply by raising the possibility of potential negative effects (as done by the data collection team) it might have provided farmers with a reason to express such misgivings. In this sense, demographic factors such as educational level might affect how the farmers respond. For instance, the fact that Ugandan farmers were generally more highly educated might have provided them with better basis for understanding, interpreting and responding to the information given and the questions asked during the survey.

Finally, when investigating the potential connection between awareness and level of concerns, it is important to keep in mind that the response rate was much higher for the latter. For instance, close to all of the Ugandan and Tanzanian farmers replied to the question regarding concerns associated with GM crops, when in fact there were only 13 and 114 farmers aware of the technology, respectively. Furthermore, as already touched upon, another consideration when comparing across countries is the difference in sample size.

Common for farmers across countries were high levels of concerns about having to buy new, good quality seeds every season (Fig. 24.12, 24.16 and 24.24), even in cases where" intellectual property rights protection for seed companies and loss of Farmers' Rights" was not considered a particular important concern (e.g. among Tanzanian farmers). The latter finding could indicate that farmers misunderstood the meaning of the issue raised, though it was exemplified with "loss of control over re-use of seeds". However, there were significant differences in the level of concern across counties in Kenya (Appendices 1, Table D.6); the majority of farmers in Meru and Tharaka-Nithi expressed low or no concerns about having to buy new seeds every season (Fig. 24.12), which they explained by already being tied into seed companies. This is interesting in terms of the discussion on IP protection of transgenic plants and planting material compared to those governing improved and hybrid varieties (Chapter 13, section 13.3). Still, the overall finding is a testament of the importance of the debate on the potential socio-economic impacts of IPRs.

The potential effect of risk perception on perceptions and acceptance of GM crops

The ability to assess the effect that the level of concern have on perceptions and acceptance of GM crops was confounded by the fact that most farmers consistently expressed high (Kenya and Uganda) or low levels of concerns (Tanzania) (Table 24.6, 24.8 and 24.10, respectively), thus making the variation upon which to estimate the correlation very small. Based on this consideration, it was decided to forego such investigations.

Keeping in mind that no valid conclusion can be drawn without statistical tests, a simple eye-balling of the data did not reveal any apparent relationship between the level of concern and impressions and acceptance of GM crops among Kenyan farmers. For instance, all farmers of Tharaka-Nithi and Meru were "very concerned" about all issues raised (Appendices 1, Appendix D.3), but still found GM crops favourable (Fig. 24.7), displayed a high WTG (Fig. 24.9), believed that GM crops could improve the quality of life of farmers (Fig. 24.10), and showed strong support for commercialisation (Fig. 24.11). However, in Tanzania, farmers from Babati generally expressed lower levels of concerns than farmers from Karatu (Appendices 1, Appendix D.4), which could possibly have contributed to the higher level of positive perceptions recorded in the former (Fig. 24.19-24.23). Note that due to the coherence among groups (i.e. expressing very similar levels of misgivings) it was not possible to assess any potential effects of the level of concern by eye for the Ugandan farmers.

Still, as previously touched upon, the majority of Kenyan and Ugandan farmers expressed high levels of positive perceptions and acceptance of biotech crops despite the high levels of concerns. This is consistent with studies by Kimenju & Groote (2008), Lewis *et al*. (2010), Kikulwe *et al*. (2011) and Kimenju *et al*. (2011), but not with Kagai (2011), the United Republic of Tanzania (2012) and Mnaranara *et al*. (2017). Possibly, the high level of positive attitudes despite several misgivings may be a reflection of factors such as hypothetical bias (Box 24.1).

Risk tolerance. As a final notion on the topic of risk perception, it could have been interesting to investigate risk tolerance – how big of a risk are consumers and farmers in East African countries willing to take? Some studies argue that poor farmers are more risk averse due to low savings and lack of food surplus, which might make them prefer "safer" and traditional varieties, even when these have lower yields (Cleveland & Soleri, 2005; Soleri *et al*., 2005). If this is the case, would GM seeds and food products have to be sold at discounted prices? Or would farmers – presupposing that they have been given the appropriate education and background knowledge on biotech crops – perceive such crops as having a greater direct benefit and thus accept conventional or even premium prices?

24.4.3. Sources of information on biotech crops and its potential impact on farmer attitudes and perceptions

The most important source of information on genetically modified (GM) crops among Kenyan, Ugandan and Tanzanian farmers

Consistent with the studies by Kagai (2011) and Kimenju *et al*. (2011) (Chapter 10), the media was a particularly important information channel among Kenyan farmers (Table 24.7), which could indicate that the media landscape is more advanced, reaches a wider audience, and/or has a greater coverage of issues related to agricultural biotechnology compared to in Uganda and Tanzania. Still, several of the Ugandan farmer groups reported governmental debates being broadcasted on the radio as their main source of information (Table 24.9). Thus, as opposed to what is suggested by Kimenju *et al*. (2011) (Chapter 10), it appears as if radio may have some impact on parts of the rural population in Uganda. However, as the survey sites were located around the capital of Kampala, it could be that the radio reception is greater here than in more remote areas.

Tanzanian farmers differed somewhat in that NGOs were considered the primary source of information (though only by a single percentage when compared to the media) (Table 24.11). This may appear inconsistent with the study by the United Republic of Tanzania (2012) which found NGOs to be the least important source of information. However, the study is not directly comparable as it included a range of stakeholders in addition to farmers. Furthermore, 5% of participants did consider NGOs as a source of information on GMOs.

An important consideration when assessing the above-mentioned findings is the response rate. It would be natural to assume that mostly GMO aware farmers would feel in a position to reply to the question about the source from which they receive/gather information on GM crops. However, it was only for the Ugandan survey that one could feel relatively confident that only GMO aware farmers had replied (though this cannot be ascertained without individually-labelled data), while the number of respondents at times somewhat exceeded the number of GMO aware farmers in the Kenyan and Tanzanian surveys. This could be a result of the question not being explicitly framed in a way which presupposed awareness. Thus, it could have been interpreted as where farmers *would* gather information from, for which the reply might have been based on an estimated guess (e.g. on the basis of where farmers had heard of related issues in past).

A consequence of the higher-than-expected response rate was that the percentages were calculated on the basis of the total number of farmers in the Kenyan and Tanzanian surveys. This approach does not provide a true representation of where farmers had been made aware of GM crops, but does provide an indication of the most important information channels among farmers.

The potential impact of the type of information channel on farmer attitudes and perceptions

The ability to assess the correlation between various information channels and farmers attitudes was confounded by the higher-than-expected response rate, as well as the fact that there were a number of response alternatives and that farmers could submit more than one response (Chapter 25, section 25.1.5.3 for more information). Thus, it was decided to forego the statistical analyses. Instead, an attempt to assess any possible relationships by eye was carried out. In this respect, it was assumed the responses represented the source of information for which farmers had been made aware of, and/or had acquired information on, GM crops.

However, such an evaluation was challenging for the Kenyan farmer data, as most groups reported a range of various information channels (Table 24.7), thus making it difficult to assess both the information channels and the farmer groups in relation to each other. Still, Kitui was rather unique in that NGOs was considered the major source of information, which could lead one to believe that farmers would have been exposed to a high degree of negatively biased information (Chapter 9). However, a large majority of farmers in this county had a favourable impression of biotech crops (Fig. 24.7).

In Tanzania, “the media” was more prominent in Babati than in Karatu, while “statements by governmental officials” and “seed/input companies” were considered more important in the latter (Table 24.11). However, in what way such information channels might have contributed to swaying the opinions of farmers is hard to assess; little is known about the balance of reporting on GMO issues by the Tanzanian media (though the study by Randall (2014) found that the major Tanzanian paper the Citizen usually took a negative stance) (Chapter 10), while the same is true for governmental officials. In the case of “seed/input companies”, one might expect such an information channel to largely convey positively inclined information. However, in what way this has contributed to the favourable impressions recorded in Karatu is not possible to discern without a more thorough analysis using individually labelled data.

In Uganda, farmers which reported “the media” as their source of information found GM crops both favourable and unfavourable (Table 24.9), which is perhaps as expected as news reporting can be biased towards both the negative and positive (or potentially portray a more balanced view) (Chapter 10), thus its effect on the receiving audience is not a given. In addition to “the media”, group 1 and 6 reported governmental debates (being broadcasted on the radio) as a source of information (Table 24.9), whereby negative effects of biotech crops (e.g. health implications) had been the centre of attention (data collection team, pers. comm.). This is consistent with the finding by DeRosier *et al*. (2015) whereby news stories which employed governmental officials as the source of reference were more likely to report risks (Chapter 10), and is further likely to help explain why all farmers of group 1 and the majority of group 6 had an unfavourable impression (Appendices 1, Fig. D.5.2).

Group 8 was unique in that the whole range of sources was considered channels of information (Table 24.9). In other words, it is likely that farmers of this group would have been exposed to a wide range of information about GM crops (i.e. both risks and benefits), which might have resulted in a more balanced view of the technology or, alternatively, confused rather than enlightened farmers as suggested by certain authors (e.g. Hossain & Onyango, 2004; Costa-Font *et al*., 2008). Interestingly, farmers of group 8 remained rather divided in terms of their attitude towards GM crops (i.e. four participants had a favourable impression, while the remaining six had an unfavourable impression) (Appendices 1, Fig. D.5.2). Thus, it could be that farmers have picked up on different types of information, or weighed the information differently, which subsequently might have influenced their perception and attitude towards GMOs. Finally, the respondent of group 10 was the only to report "researchers/extension workers" as the only information channel, as well as finding GM crops favourable (Appendices 1, Fig. D.5.2), which tally well with the expected tendency of researchers and extension workers to convey mostly positively inclined information.

24.4.4. The potential effect of increased knowledge and acquisition of novel information on perceptions and acceptance of genetically modified (GM) crops

In consumer behavioural theory, it is assumed that increased knowledge results in increased acceptance (Moerbeek & Casimir, 2005). However, some authors argue that this principle does not apply to GMOs due to the level of uncertainty about the long-term consequences, which might cause consumers that are more knowledgeable to express higher levels of concerns (Bucchi & Neresini, 2002; Moerbeek & Casimir, 2005). Yet, Koivisto-Hursti and Magnusson (2003) demonstrated a direct positive relationship between knowledge of GM technology and support for GM applications among Swedish consumers.

In terms of the questionnaire at hand, the best indicator of the effect of increased knowledge would be to assess the results obtained for the question "do positive results obtained from countries such as Burkina Faso (whereby planting of Bt Cotton has led to an average increase in yield of almost 20%, a reduction in pesticide-use of ~67%, and a 51% increase in income levels compared to conventional cotton) make you want do demand such crops yourself?"; both by itself, as well in relation to the subsequent and final question on whether farmers support the commercialisation of GM crops.

A vast majority of farmers said that learning about results obtained by Bt cotton-adopting farmers in Burkina Faso made them want to demand such crops themselves (Fig. 24.13, 24.17 and 24.25). The acquisition of this novel information might have led to an increase in the perceived benefit of GM crops, and could help explain the subsequent high levels of support for commercialisation. Indeed, the simulation model found a positive and significant correlation between the fraction of Kenyan farmers that reported of an increase in demand and the fraction that supported the commercialisation of the technology (Appendices 1, Table 9.D.1), which appear consistent with Moerbeek & Casimir (2005) and Koivisto-Hursti & Magnusson (2003). This finding could further imply that attitudes are likely to change as awareness campaigns are implemented and commercialised products become available, as this will lead to increased experience with, and knowledge of, the technology (Bredahl *et al*., 1998). However, such a correlation was not found for Ugandan farmers

(Appendices 1, Table 9.D.2) (note that a similar investigation was not carried out for Tanzanian farmers as there were too little variation upon which to conduct a correlation analysis).

Additionally, other types of information acquired during the onset and progression of the questionnaire is likely to have influenced farmers' attitudes (e.g. acquiring basic knowledge about the concept of genes and GM crops provided by the data collection team). This could help explain the high WTG and why the majority of farmers perceived GM crops as a way to improve the quality of life of farmers (i.e. questions asked *before* farmers were given information about farmers in Burkina Faso). Furthermore, despite trying to remain as objective and unbiased as possible, the data collection team might have influenced the attitudes and perceptions of farmers. Additionally, the opinions of farmers – perhaps particularly of those that were naturally more vocal, the village leaders and contact farmers – may have influenced the perceptions of the other participants, which could further explain the high degree of coherence observed within certain groups.

The possible effect of naivety on receptiveness to novel information on genetically modified (GM) crops

The simulation model found significant differences in the level of impact that the information about GM crop adoption in Burkina Faso had on farmer demand within and between the study countries (Appendices 1, Table D.6-D.8).

Interestingly, the information appeared to have the highest level of impact among Tanzanian farmers (i.e. led to the biggest increase in demand), especially so in the district of Babati (Fig. 24.25). This finding is likely to reflect a number of considerations, but one could hypothesise that naivety might be an explanatory factor. For instance, Huffman *et al*. (2007) found that uninformed respondents in the US were more susceptible to information from external sources than informed ones. Additionally, reporting on GM food risks by the media has been shown to have the highest level of impact on receivers exhibiting the lowest level of prior knowledge (Frewer *et al*., 2002; Vilella-Vila & Costa-Font, 2008). Lusk *et al*. (2004) also found that participants (i.e. the general public from the US, UK and France) who already had positive attitudes towards GM food products or lacked prior subjective information were more receptive to new and positive information, as opposed to those that held negative attitudes (which were less willing to accept novel information).

However, the question "are you aware of GM crops" does not provide information about the level of knowledge nor does it ascertain the respondents' understanding of GMOs, thus is somewhat poorly suited to assess the possible effect that naivety may have on receptiveness to new information. Still, when such correlation analyses were carried out among Kenyan and Ugandan farmers, no significant relationships were found (Appendices 1, Table 9.D.1 and 9.D.2). A simple assessment of the data by eye further supported the lack of any consistent trends between level of awareness and the reported increase of demand in the various Kenyan counties (Fig. 24.6 and Fig. 24.13, respectively). For the Tanzanian survey, the highest increase in demand was recorded in Babati, which was also the district with the lowest level of awareness. However, any potential relationship between the two was not possible to assess due to low level of variation to base the analysis on (i.e. none of the farmers reported of no increase in demand).

As previously discussed, the level of concern could be an indicator of naivety, as well as a potential cause and indicator of negative attitudes towards GM crops. If the former assumption holds true, it could help explain the high level of farmer demand in response to novel information among

Tanzanian farmers (who also expressed low levels of concerns). This could further explain why the increase in demand was not as high among Ugandan farmers who, despite being the least aware, expressed very high levels of concerns, which implies that farmers *do* have some prior knowledge and/or (mis)perceptions of biotech crops. Such observations might touch upon similar ideas as observed by Lusk *et al*. (2004), whereby those with prior negative attitudes are less willing to accept novel information.

Finally, a potential indicator of the effect of prior attitudes on receptiveness to novel information is the relationship between farmer impressions of GM crops and the level of increase in demand in response to information about GMO adoption in Burkina Faso. Consistent with Lusk *et al*. (2004), a significant correlation was found between the fraction of Kenyan farmers that reported of an increase in demand for GM crops and the fraction having a favourable impression of the technology, while a negative correlation was found for the fraction of farmers with an unfavourable impression (Appendices 1, Table 9.D.1). For instance, farmers in Nyeri County – which exhibited the second least favourable attitudes towards GM crops after Machakos (Fig. 24.7) – reported of the lowest increase in demand (Fig. 24.13). Following Nyeri, the increase in demand among farmers in Muranga (with the 3rd least favourable attitudes) and Machakos was in fact the lowest recorded, but still substantial at 71% and 73%, respectively (Fig. 24.13). However, a similar significant effect was not observed among Ugandan farmers (Appendices 1, Table 9.D.2) (as before, Tanzania was excluded from this analysis due to low levels of variation).

24.4.5. The effect of demographic factors on awareness, attitudes and perception of genetically modified (GM) crops

The simulation model demonstrated relatively few consistent trends in terms of demographic effects on awareness and opinions of farmers, with the exception of a few cases in which education, sex, cultural leaning and marital status appeared to have an effect. That being said, the fact that the groups being compared were found to be significantly different confounds the ability to draw any valid conclusions based on such findings (Chapter 25, section 25.1.5.3). Despite this, it was considered valuable to investigate the results further in an attempt to help explain the observed differences and/or similarities within and between study countries.

Education

It has been argued that the level of education is likely to impact on the receiver's access to and ability to analyse information, and thus may influence awareness and attitudes (Steenkamp, 1997; Zhong *et al*., 2002). However, the effect can work in both directions, as the respondent might become better at identify both potential risks (as suggested in section 24.4.4) and benefits (Berrier, 1987; Koivisto-Hursti & Magnusson, 2003; Stewart, 2000). It has further been suggested that risks that are outside the control of the individual are more heavily weighed than benefits during consumer decision-making (e.g. Huffman *et al*., 2002).

Several studies have found an association between the level of education and positive perceptions of GM crops (e.g. Hossain *et al*., 2002; Traill *et al*., 2004; Torres *et al*., 2006; Kimenju & De Groote, 2008; Njoka *et al*., 2011), also among farmers (Fernandez-Cornejo & McBride, 2000; Hubbell *et al*., 2000; Fernandez-Cornejo *et al*., 2001; Qaim & de Janvry, 2003; United Republic of Tanzania, 2012). Contrary, other studies have demonstrated a negative effect of increased educational level. For instance, Kikulwe *et al*. (2011) found that willingness-to-purchase GM bananas decreased with an increase in education level among Ugandan consumers, which is consistent with Krishna & Qaim

(2008) [Indian consumers] and Bugge & Rosenberg (2017) [Norwegian consumers]. Paarlberg (2008) has previously argued that the African urban elite may exhibit negative attitudes due to having opinions more in line with the European viewpoints.

Kenyan and Ugandan farmers were generally more highly educated than Tanzanian participants (Table 24.1, 24.2 and 24.3, respectively), while a higher number of Kenyan farmers exhibited secondary level education compared to Ugandans. Uganda had the highest number of farmers with higher education, though only by a single percentage compared to the Kenyan survey. Additionally, the "higher education" category does not provide information about the composition (i.e. whether some college, Bachelor, Master or PhD level education), as it was decided to collapse these for the purpose of analysis. A closer look at the data revealed that most of the Ugandans with higher education had achieved some college, while a few had Bachelor degrees (data not shown). The same was true for Kenyan farmers, though a few had also obtained Masters. In fact, Tanzania was the only country in which a few of the farmers had achieved education at the PhD level (data not shown). Furthermore, Uganda was the only country in which some of the farmers had no formal education at all.

The present study found a significant effect of education on the level of awareness among Kenyan and Ugandan farmers (Appendices 1, Table D.9.1 and D.9.2, respectively). It appeared as if farmers with secondary level education exhibited a higher level of awareness than those with primary education (note that correlation was only weakly significant for Ugandan farmers). Furthermore, Kenyan farmers with secondary level education seemed to have a more favourable impression of GM crops than those with lower levels of education (Appendices 1, Table D.9.1). In Uganda on the other hand, there was a negative correlation between the fraction of farmers with higher education ((i.e. some college, Bachelor, Master and PhD) and the fraction that supported commercialisation. In Tanzania, there was a positive correlation between the fraction of aware farmers and the fraction of farmers with higher education for logit transformed data (Appendices 1, Table D.9.3), which could possibly help explain why the level of awareness was higher in Babati compared to Karatu (Fig. 24.18), as more farmers had achieved higher education in the former. That being said, there was a lack of a consistent and linear relationship between awareness and an increase in education; besides being non-significant, the correlation between awareness and farmers with primary education was positive, while it was negative for those with secondary level education (Appendices 1, Table D.9.3).

The findings from this study suggest that higher education may have a positive impact on awareness and impressions of GM crops, which is consistent with a number of studies (e.g. Fernandez-Cornejo & McBride, 2000; Hubbell *et al*., 2000, Fernandez-Cornejo *et al*., 2001; Hossain *et al*., 2002; Qaim & de Janvry, 2003; Traill *et al*., 2004; Torres *et al*., 2006; Kimenju & De Groote, 2008; Njoka *et al*., 2011; United Republic of Tanzania, 2012). The effect of education appeared particularly prominent among Kenyan farmers, and the higher level of formal education among Kenyan farmers could be part of the explanation for the higher level of awareness and at times favourable impressions of the technology recorded here.

Religion

Please see Chapter 12.

Cultural leaning

As many as ~38% of Ugandan farmers considered themselves conservative culturally, while this group only constituted ~1% and ~2% of Tanzanian and Kenyan farmers, respectively (Table 24.2, 24.1 and 24.3, respectively). This might indicate that Ugandan farmers have bigger reservations about the use of biotech seeds if these are perceived as a threat to culturally important cultivars and traditional farming practices. Still, Ugandan farmers expressed relatively low levels of religious/cultural concerns (though one has to consider the religious aspect of this question, which might have reduced its perceived level of importance; see Chapter 12, section 12.4). That being said, the data collection team made several notes regarding cultural misgiving during the Ugandan survey, including sourcing of genes from culturally unaccepted yams for transfer into the cooking banana 'Matooke', and fear of potential negative impacts of biotech crops on indigenous varieties.

Interestingly, in Kenya, culturally conservative farmers appeared to exhibit less favourable impressions of GM crops, were less willing to grow GM crops and displayed less support for commercialisation (similar investigations for culturally liberal farmers were positive, but not significant) (Appendices 1, Table 9.D.1). This finding could be part of the reason why farmers in Machakos – which was the only county in which farmers characterised themselves as conservative (Table 24.1) – exhibited the lowest level of favourable attitudes towards GM crops (Fig. 24.7). In Uganda, there was a weak, positive correlation between the fraction of culturally moderate farmers and the fraction having a favourable impression of the technology for logit transformed data (Appendices 1, Table 9.D.2). However, though not significant, the relationships between both culturally liberal and conservative farmers and the level of favourable impressions were negatively correlated, thus there appear to be a lack of any linear and positive relationship between an increase in liberal attitudes and favourable impressions.

Marital status

Most studies have failed to find a significant association between marital status and acceptance of GMOs among consumers (e.g. Chen & Chern, 2002; Baker & Burnham, 2002). However, Mulaudzi & Oyekale (2015) found a significant and positive relationship between marital status and adoption of GM maize among farmers in South Africa.

Marital status could be an indicator of whether farmers have children or not, which might influence their level of risk-aversion and consequently their perception of biotech crops. For instance, Dosman *et al*. (2001) demonstrated that the level of perceived risks associated with food safety increased with the number of children within a household, and Chen & Chern (2002) showed empirically that the number of children had a significant negative effect on willingness-to-consume GM food among US consumers. Contrary, Baker & Burnham (2002) did not find a statistically significant correlation among US consumers. However, there is a lack of studies investigating the effect that the number and age of children may have on acceptance of biotech crops in developing countries. For instance, in a country with high child mortality and food insecurity, will parents with fewer or younger children be more risk averse or consider GM crops as an attractive solution?

If one assumes that married farmers are more risk-averse due to having children, then one could hypothesise that single farmers will be more positive towards GM crops. This could appear to hold true for Ugandan farmers, where there was a significant and negative correlation between the fraction of married farmers and support for commercialisation (Appendices 1, Table D.9.2). However, a similar trend was not observed in terms of farmer impressions of biotech crops or WTG. Furthermore, the relationship between single farmers and the support for commercialisation was also negative, though not significant. In other words, the effect of marital status remains rather unclear, thus further investigation is needed.

Farm size

A few studies have found a positive association between farm size and the likelihood of adopting biotech crops, including Hubbell *et al*. (2000), Fernandez-Cornejo *et al*. (2001), Marra *et al*. (2001) [Bt cotton in the US], Payne *et al*. (2003) [Bt maize in the US], and Qaim & de Javry (2003). Such findings could imply that farmers with larger landholdings are more open to adopting GM crops due to having more available land for cultivation. Additionally, a large farm size might indicate higher affluence and thus more resources for investing in novel technology. Contrary, the study by Mulaudzi & Oyekale (2015) found that an increase in farm size reduced the adoption rate of GM maize in South Africa. The authors proposed that the farmers wanted to grow other crops that generated greater returns than maize.

One could imagine that farmers with small landholdings are faced with even greater issues related to food insecurity than those with larger farms. On one hand, such farmers might have the most to lose if adoption failed as they lack a "safety net" in the form of quantity and diversity of crops, which could make them more risk-averse due to the uncertain outcomes associated with the adoption of new technology. On the other, such farmers could have the most to gain from adopting GM crops (presupposing that they deliver the proposed benefits), which could make the perceived benefit even greater.

In the present study, it was only the data obtained from the Tanzanian survey which allowed for an investigation of the effect of farm size (the exact number of farmers that exhibited certain ha of farm land was not available for the Ugandan and Kenyan surveys), whereby no significant correlations were found. Thus, farm size does not appear to impact on Tanzanian farmer impressions of GM crops, while further investigations are needed among Ugandan and Kenyan farmers.

Sex

Studies have found that men are generally more positive towards science and technology compared to women (Cockburn & Ormrod, 1995; Lubar, 1998; Hoban, 2004), which also seems to apply to biotechnology and GM foods (Hamstra, 1998; James & Buton, 2003; Moerbeek & Casimir, 2005; Gaskell *et al*., 2010). For instance, Hossain *et al*. (2002) found that male, American consumers were more likely to buy and consume GM food products than women. This finding is consistent with several studies, including Pew Initiative on Food and Biotechnology (2001a) [US consumers], Grimsrud *et al*. (2002) [Norwegian consumers], Koivisto-Hursti *et al*. (2002) [Swedish consumers], Mucci *et al*. (2004) [Argentinian consumers], Christoph *et al*. (2008) [German consumers], Krishna & Qaim, 2008 [Indian consumers], and Bugge & Rosenberg (2017) [Norwegian consumers], as well as with perception surveys conducted in the East African region (e.g. Kikulwe *et al.*,2011; Njoka *et al*., 2011; United Republic of Tanzania, 2012).

A few studies have tried to elaborate on why gender-based differences exist. Anunda *et al*. (2010) argues that women, especially from developing countries, are overall less knowledgeable, interested and supportive of science and technology. Casimir & Dutilh (2003), Hwang *et al*. (2005) and Moerbeek & Casimir (2005) touch upon similar ideas, i.e. that women may have bigger concerns due to greater responsibilities in acquiring and preparing food for their families, and that they may exhibit more long-term perspectives than men. Moerbeek & Casimir (2005) also found that increased knowledge resulted in a higher level of acceptance of GM foods, but more so for men than women, while Simon (2010) found that an increase in knowledge resulted in more pessimistic views among women. Thus, the effect of gender appears to interact with other factors such as level of knowledge and education, which complicates the ability to discern its effect on perceptions and acceptance. One could further imagine that that gender-related differences in and outside the home (e.g. feeding and tending to children and access to education) are more prominent in certain East African communities compared to in developed countries.

The present study found significant relationships between sex, awareness and acceptance of GM crops among Ugandan (Appendices 1, Table 9.D.2 and 9.D.3, respectively). In Uganda, females appeared less aware than male farmers, but the former seemed to express a higher level of support for commercialisation. Thus, interestingly, the results obtained from this study indicate that sex is not always an influential factor, and the results obtained among Ugandan farmers appear inconsistent with studies that have found women to be more negative than men.

Age

Unfortunately, it was not possible to determine the effect of age as the information was usually given as a range (i.e. from the youngest to oldest) or as a cut-off point (i.e. above or below a certain age). Other studies have demonstrate contradictory results; Hossain *et al*. (2002) found that younger (<35 y/o) participants were more acceptant of GM food products, which is consistent with studies by e.g. Grimsrud *et al*. (2002), Torres *et al*. (2006), Gaskell *et al*. (2010), Kikulwe *et al*. (2011), Njoka *et al*. (2011), United Republic of Tanzania (2012), and Bugge & Rosenberg (2017). Such findings could tally well with the age of the technology advocacy. However, some studies have demonstrated the opposite effect (Olofsson & Olsson, 1996; James & Buton, 2003; Christoph *et al*., 2008), while a few studies have found no significant relationship at all (e.g. European Commission, 2008). Payne *et al*. (2003) and Alexander & Mellor (2005) are among the few studies that have found age to be a positively significant factor on the adoption of GM crops by farmers, though only up to a certain threshold. Payne *et al*. (2003) found that the likelihood of adoption reached a maximum at 49 y/o, while Alexander & Mellor (2005) found that adoption rate increased with age for young farmers (likely due to an increase in experience), but declined from about 48 y/o (i.e. as farmers were closing in on the age of retirement, by which time the receivable returns from investing in novel technology would start to diminish).

24.5. Results: Stakeholder survey

The next sections will consider the results obtained from the perception study conducted among East African stakeholders, including researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

24.5.1. Awareness and general attitude towards genetically modified (GM) crops

All stakeholders were aware of GM crops, which is as expected as participants were chosen on the basis of their involvement in the topic. 5.1% of stakeholders “strongly disagreed” that “GM crops should play a role in addressing issues of food security, hunger and poverty in their country”, while 23.1% “somewhat agreed”, 25.6% “agreed” and 44.9% “strongly agreed” (1.3% did not respond; not shown in Fig. 24.26) (Fig. 24.26).

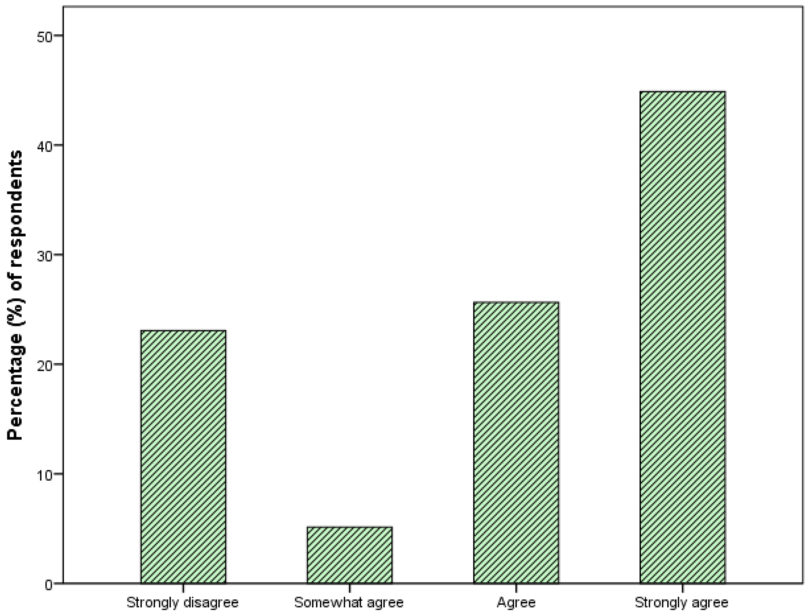


Figure 24.26. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that agreed that genetically modified (GM) crops should play a role in addressing issues of food insecurity, hunger and poverty in East Africa. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. Response rate: ~99% (77 out of 78 respondents).

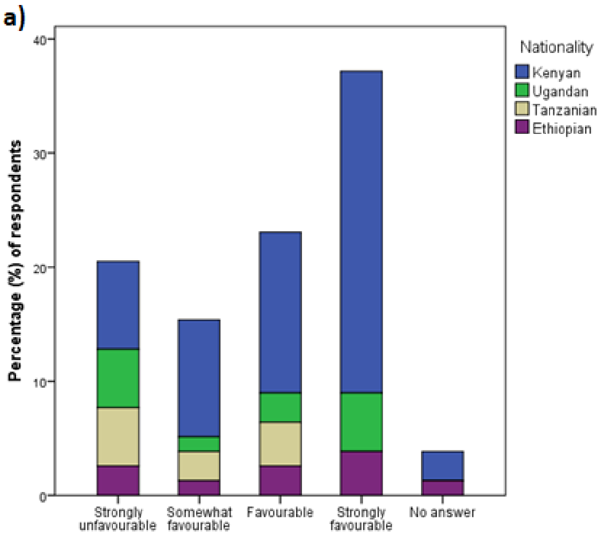
There were significant differences in the opinions expressed by stakeholders on the basis of occupation, but not on the basis of nationality (Appendices 1, Table E.4). Note that this question was used to group participants into perception groups, thus please refer back to section 24.2.6 for more information.

24.5.2. Opinions of the commercialisation of genetically modified (GM) food and cash crops

20.5% of stakeholders found the commercialisation of GM food crops “strongly unfavourable”, 15.4% “somewhat favourable”, 23.1% “favourable” and 37.2% “strongly favourable” (3.8% did not respond) (Fig. 24.27a). 16.7% of stakeholders found the commercialisation of GM cash crops “strongly unfavourable”, 2.6% “somewhat favourable”, 20.5% “favourable” and 50% “strongly favourable” (10.3% did not respond) (Fig. 24.27b).

There were no significant differences in opinions of the commercialisation of GM food and cash crops on the basis of nationality (Appendices 1, Table E.4). Of those that found the commercialisation of GM food crops “strongly unfavourable”, six were Kenyan (37.5%), four were Ugandan (25%), four were Tanzanian (25%) and two were Ethiopian (12.5%). Of those that found it “somewhat favourable”, eight were Kenyan (~67%), two were Tanzanian (~17%), one was Ugandan (~8%) and one was Ethiopian (~8%). Of those that found it “favourable”, 11 were Kenyan (~61%), three were Tanzanian (~17%), two were Ugandan (~11%) and two were Ethiopian (~11%). Finally, of the stakeholders that found the commercialisation of such crops “strongly favourable”, 22 were Kenyan (~76%), four were Ugandan (~14%) and three were Ethiopian (~10%). Of the three participants that gave no response, two were Kenyan (~67%) and one was Ethiopian (~33%) (Fig. 24.27a).

Of those that found the commercialisation of GM cash crops “strongly unfavourable”, five were Kenyan (~38%), four were Tanzanian (~31%), three were Ugandan (~23 %) and one was Ethiopian (~8%). Of those that found it “somewhat favourable”, one was Ugandan (50%) and one was Ethiopian (50%). Of the participants that found the commercialisation of such crops “favourable”, nine were Kenyan (~56%), three were Ugandan (~19%), two were Tanzanian (~13%) and two were Ethiopian (~13%). Finally, of the respondents that found commercialisation “strongly favourable”, 29 were Kenyan (~84%), five were Ethiopian (~13%), three were Ugandan (~8%) and two were Tanzanian. Eight participants gave no response, of which six were Kenyan (75%), one was Ugandan (12.5%) and one was Tanzanian (12.5%) (Fig. 24.27b).



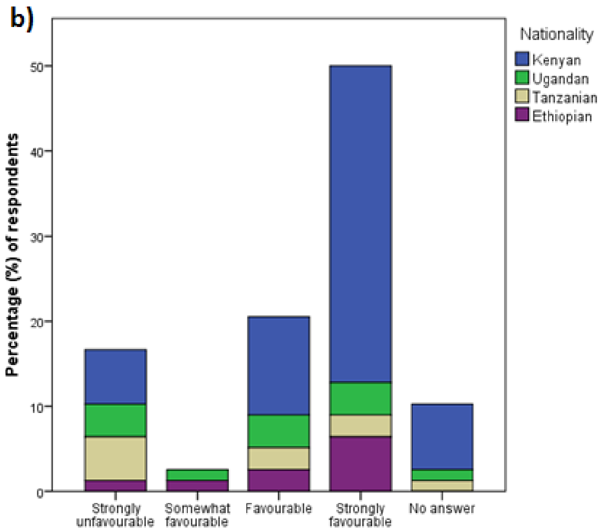


Figure 24.27. Opinions of the commercialisation of genetically modified (GM) a) food crops and b) cash crops by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were no significant (NS) differences in the opinions of the commercialisation of GM food on the basis of nationality (p>0.05). Response rate: ~96% (75 out of 78 respondents). **b)** There were NS differences in the opinions of the commercialisation of GM cash crops on the basis of nationality (p>0.05). Response rate: ~90% (70 out of 78 participants).

There were significant differences in the opinions of the commercialisation of GM food and cash crops on the basis of the participants' occupation and perception group (PG) (Appendices 1, Table E.4). Most commonly, the majority of agricultural researchers, civil servants employed in the public/private sector related to agriculture and extension workers made responses in favour of commercialisation, while the majority of those employed in an NGO found commercialisation "strongly unfavourable" (Appendices 1, Fig. E.5.7.1a+b). In the case of perception group, the majority of respondents from PG1 and PG4 found the commercialisation of GM food and cash crops "strongly unfavourable" and "strongly favourable", respectively (Appendices 1, Fig. E.5.7.2a+b).

Additionally, there were significant differences in the opinions of the commercialisation of GM cash crops on the basis of the respondents' knowledge of agriculture and rural life (Appendices 1, Table E.4). The majority of those that "knew enough" or characterised themselves as "very knowledgeable" found the commercialisation "strongly favourable" (i.e. ~53% and ~54%, respectively), while all of those that did "not know much" about agriculture and rural life found commercialisation "favourable" (or did not respond) (Appendices 1, Fig. E.5.7.3).

24.5.3. The importance of conventional measures and the development of regulatory and infrastructural capacity in East Africa

Conventional measures

33.3% of stakeholders “strongly disagreed”, 9.0% “somewhat agreed”, 17.9% “agreed” and 39.7% “strongly agreed” that “conventional measures (e.g. conventional breeding, increased use of fertilisers, improved crop management, better irrigation systems, improved mechanisation and tools) should be fully exploited before the use of biotechnology” (1.3% did not respond; not shown in Fig. 24.28) (Fig. 24.28).

There were no significant differences in stakeholder opinions on the basis of nationality (Appendices 1, Table E.4). Of those that “strongly disagreed”, 19 were Kenyan (~73%), four were Ethiopian (~15%), two were Ugandan (~8%) and one was Tanzanian (~4%). Of the stakeholders that “somewhat agreed”, four were Kenyan ~57%, two were Ethiopian (~29%) and one was Ugandan (~14%). Of the respondents that “agreed”, seven were Kenyan (50%), three were Ugandan (~21%), two were Tanzanian (~14%) and two were Ethiopian (~14%). Finally, of those that “strongly agreed”, 19 were Kenyan (~61%), six were Tanzanian (~19%), five were Ugandan (~16%) and one was Ethiopian (~3%).

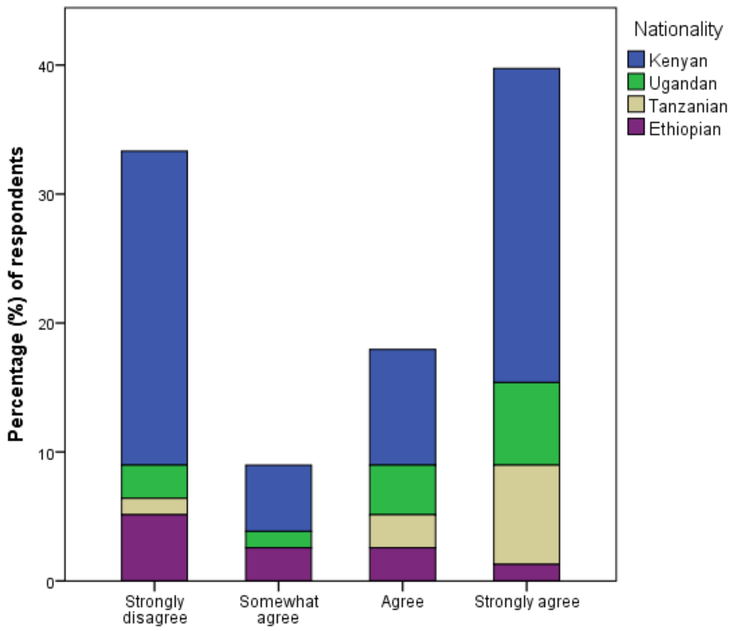


Figure 24.28. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that agreed that conventional measures (e.g. traditional breeding, increased use of fertilisers, improved crop management, better irrigation systems, improved mechanisation and tools) should be fully exploited before the use of biotechnology. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the opinions of stakeholders on the basis of nationality ($p>0.05$). Response rate: 100% (78 out of 78 respondents).

There were significant differences in stakeholder opinions on the basis of the respondents’ occupation and perception group (Appendices 1, Table E.4). The majority of agricultural researchers (~52%) and respondents from PG4 (~57%) “strongly disagreed” (while the remaining respondents spread relatively evenly across the other response categories), while the majority of civil servants from the NGO sector (~71%) and respondents from PG1 (~89%) "strongly agreed" (Appendices 1, Fig. E.5.8a+b). Additionally, the majority (~55%) of extension workers "strongly agreed", while civil servant employed in the public/private sector related to agriculture were found to spread across response categories, but with a slight majority of respondents "strongly disagreeing" (Appendices 1, Fig. E.5.8a+b).

Regulatory and infrastructural capacity

35.9% of stakeholders "strongly disagreed" that "East African countries should fully develop their regulatory capacity and improve their infrastructure before adopting GMOs", while "14.1% "somewhat agreed", 16.7% "agreed" and 32.1% "strongly agreed" (Fig. 24.29).

There were no significant differences in the opinions expressed by stakeholders on the basis of nationality (Appendices 1, Table E.4). Of those that "strongly disagreed", 22 were Kenyan (~78%), four were Ugandan (~14%), one was Tanzanian (~4%) and one was Ethiopian (~4%) (Fig. 24.29). Of those that "somewhat agreed", six were Kenyan (~54%), three were Ethiopian (~27%), one was Ugandan (~9%) and one was Tanzanian (~9%). Of the stakeholders that "agreed", seven were Kenyan (~54%), three were Ethiopian (~23%), two were Tanzanian (~15%) and one was Ugandan (~8%) (Fig. 24.29). Finally, of those that "strongly agreed", 14 were Kenyan (56%), five were Ugandan (20%), four were Tanzanian (16%) and two were Ethiopian (8%) (Fig. 24.29). One respondent (Tanzanian) did not have an opinion (not shown in Fig 24.29).

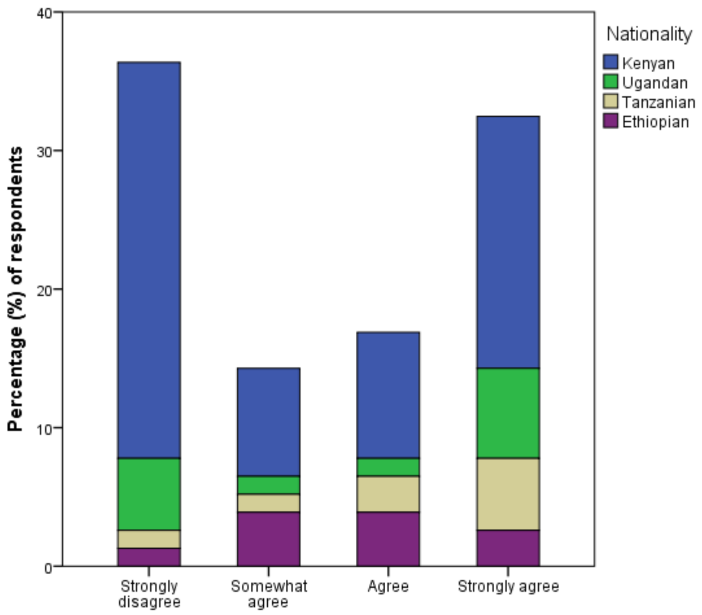


Figure 24.29. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that agreed that East African countries should fully develop their regulatory capacity and improve their infrastructure before adopting genetically modified organisms (GMOs). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the opinions of stakeholders on the basis of nationality (p>0.05). Response rate: 100 % (78 out of 78 respondents).

As before, there were strongly significant differences on the basis of the participants' perception group (Appendices 1, Table E.4). ~88% of those from PG1 "strongly agreed", while ~57% of respondents from PG4 "strongly disagreed" (several respondents from PG3 and PG4 divided themselves between "somewhat agree", "agree" and "strongly agree") (Appendices 1, Fig. E.5.9.1a). . However, unlike most questions raised thus far, no significant differences on the basis of occupation were found (Appendices 1, Table E.4; Fig. E.5.9.1b). However, there were significant differences on the basis of family background (Appendices 1, Table E.4). The majority of those with a farm family background either fell within the "strongly disagree" (~42%) or the "strongly agree" category (~34%), while ~10% and ~15% were found to "somewhat agree" and "agree", respectively (Appendices 1, Fig. E.5.9.2). Respondents from a non-farm family divided themselves relatively evenly across response categories, though the fewest number of respondents (~13%) were found to "strongly disagree" (Appendices 1, Fig. E.5.9.2).

24.5.4. Concerns associated with the adoption of genetically modified (GM) crops in East Africa

Stakeholders perceived the "development of resistance by pests and pathogens", "negative environmental effects" and "damaged relationships and loss of trade with EU" as the most pressing concerns associated with the introduction of GM crops in East Africa, while "religious/cultural concerns", "damaged relationships with neighbouring countries that oppose GM crop commercialisation" and "altered social structure" were perceived as less important (Table 24.12).

Table 24.12. Level of concerns associated with potential negative effects of genetically modified (GM) crop adoption in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not concerned	Somewhat concerned	Concerned	Very concerned	I do not know/no answer
Development of resistance by pest and pathogens	20.5 [16]	16.7 [13]	23.1 [18]	38.5 [30]	1.3 [1]
Negative health effects	32.1 [25]	10.3 [8]	17.9 [14]	32.1 [25]	7.7 [6]
Negative environmental effects	24.4 [19]	12.8 [10]	29.5 [23]	32.1 [25]	1.3 [1]
Damaged relationships and loss of trade with EU	21.8 [17]	17.9 [14]	24.4 [19]	30.8 [24]	5.2 [4]
Socio-economic reasons	30.8 [24]	20.5 [16]	20.5 [16]	21.8 [17]	6.2 [5]
Damaged relationships with neighbouring countries that oppose GM crop commercialisation	35.9 [28]	17.9 [14]	23.1 [18]	16.7 [13]	6.4 [5]
Religious/cultural concerns	41.0 [32]	20.5 [16]	12.8 [10]	16.7 [13]	9.0 [7]
Altered social structure	55.1 [43]	16.7 [13]	14.1 [11]	11.5 [9]	2.6 [2]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

There were no significant differences in the level of concern on the basis of nationality for any of the addressed issues (Appendices 1, Table E.2.1). However, there were significant differences on the basis of perception and occupational group (Appendices 1, Table E.2.1). Generally, respondents from PG4 made up the majority of those that were "not concerned" or "somewhat concerned", while respondents from PG1 usually made up the majority of those "very concerned" (Appendices 1, Table E.2.2). That being said, respondents from PG3 and PG4 often constituted a large number of those "concerned", for instance in terms of "development of resistance by pest and pathogens", "damaged relationships with neighbouring countries that oppose GM crops", "damaged relationships and loss of trade with EU" and "socio-economic reasons" (Appendices 1, Table E.2.2).

In the case of occupational group, significant effects were found in the case of "damaged relationships with neighbouring countries that oppose GM crop commercialisation", "socio-economic reasons", and "altered social structure" (Appendices 1, Table E.2.1). The majority of agricultural researchers were "not concerned" or "somewhat concerned", whereas civil servants from NGOs appeared more likely to find "socio-economic reasons" and "damaged relationships with neighbouring countries that oppose GM crop commercialisation" "concerning" or "very concerning" (Appendices 1, Table E.2.2).

Additionally, significant differences on the basis of educational level were found in the case of (i) "negative health effects", (ii) "negative environmental effects", (iii) "development of resistance by pest and pathogens", (iv) "religious/cultural concerns" and (v) "damaged relationship with neighbouring that oppose commercialisation of GM crops" (Appendices 1, Table E.2.1). In the case of (i), (iv) and (v), the majority of those with PhD level education most commonly responded "not concerned". The majority of those with secondary level education consistently expressed low levels of concerns, while the majority of those with "some college" usually expressed high levels of concerns. Respondents with Bachelor and Master degrees also expressed relatively high levels of concern in the case of "negative health effects", "negative environmental effects" and "development of resistance by pest and pathogens" (Appendices 1, Table E.2.2).

Finally, there were statistical significant differences in the level of concerns about "negative health effects" on the basis of the respondents' upbringing (i.e. whether raised in a rural village, small town or city), and for the level of concerns about "altered social structure" on the basis of the participants' sex (Appendices 1, Table E.2.1). For the former, ~7% of those growing up in a city considered health effects "very concerning", while the remaining respondents from this demographic group spread relatively evenly across the rest of the response categories (Appendices 1, Fig. E.2.1). Contrary, ~38% and 40% of those growing up in a small town and rural village were "very concerned", respectively, while ~48% and 25% were "not concerned", respectively (Appendices 1, Fig. E.2.1).

In terms of sex, ~62% of male participants were "not concerned" about "altered social structure" (while the remaining male respondents divided themselves relatively equally across the three other response categories), whereas the majority of female respondents divided themselves relatively equally between "not concerned" (~41%) and "somewhat concerned" (~36%) (Appendices 1, Fig. E.2.2).

24.5.5. Possible socio-economic changes as a result of the adoption of genetically modified (GM) crops in East Africa

The least likely socio-economic change to occur as a result of GM crop adoption was considered to be "negative impacts on women (gender inequality)" (Table 24.13). For the other proposed socio-economic changes, the majority of stakeholders perceived these as "likely" or "very likely", though the highest number of respondents was found the "not likely" category (Table 24.13). Stakeholders appeared most divided in terms of "concentration of power and capital in commercial farms", whereby nearly just as many perceived it as "not likely" and "very likely" (Table 24.13).

Table 24.13. Likelihood of socio-economic changes in East Africa as a result of genetically modified (GM) crop adoption, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not likely	Somewhat likely	Likely	Very likely	I do not know/no answer
Concentration of power and capital in commercial farms	30.8 [24]	15.4 [12]	23.1 [18]	28.2 [22]	2.6 [2]
Local smallholder Farmers' Rights are negatively affected	30.8 [30]	16.7 [13]	15.4 [12]	25.6 [20]	3.8 [3]
Increased income gap between rich and poor farmers	37.2 [29]	20.5 [16]	14.1 [11]	25.6 [20]	2 [2.6]
Women are negatively affected (gender inequality)	60.3 [47]	14.1 [11]	9.0 [7]	11.5 [9]	4.1 [4]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

There were weakly significant differences in the perceived likelihood of "women becoming negatively affected (i.e. gender inequality)" on the basis of nationality (Appendices 1, Table E.3.1). The majority of Ugandan (~55%), Kenyan (~67%) and Ethiopian (~78%) stakeholders perceived this change as "not likely". Furthermore, none of the Ethiopian respondents found it "somewhat likely" or "likely", while only a single respondent perceived it as "very likely" (Appendices 1, Fig. E.3.1). The Tanzanian participants spread somewhat more evenly across response categories, though the highest number of respondents found it "somewhat likely" (~33%) (Appendices 1, Fig. E.3.1).

Additionally, there were highly significant differences in the perceived likelihood of all socio-economic changes on the basis of the respondents' perception group (Appendices 1, Table E.3.1). Similarly to what was observed for the concerns in section 24.5.4, respondents from PG3 and PG4 made up the majority of those that considered the potential socio-economic implications as "not likely", while those that perceived the potential changes as being "very likely" were largely from PG1 (Appendices 1, Table E.3.2). Furthermore, there were significant differences in the perceived likelihood of all potential socio-economic changes expect for "increased income gap between rich and poor farmers" on the basis of occupation (Appendices 1, Table E.3.1). Generally, the majority of agricultural researchers and civil servants employed in the public/private sector related to agriculture perceived the potential socio-economic changes as "not likely" (Appendices 1, Table E.3.2). Contrary, the majority of civil servants from NGOs most commonly perceived the proposed socio-economic changes as being “very likely”, or “likely” in the case of “women becoming negatively affected” (Appendices 1, Table E.3.2).

Finally, there were significant differences in the perceived likelihood of “local smallholder Farmers’ Rights becoming negatively affected” on the basis of educational level (Appendices 1, Table E.3.1). None of those with PhD level education found this potential change “very likely” (instead, ~57% perceived it as “not likely”), while those with some college divided themselves among the “not likely” (~56%) and “very likely” (~33%) response categories (one participant replied “do not know”) (Appendices 1, Fig. E.3.2). Stakeholders with Master degrees divided themselves relatively evenly across “not likely”, “likely” and “very likely” (a single respondent found it “somewhat likely”), while participants with secondary level education spread relatively evenly across “not likely”, “somewhat likely” and “very likely” (none found it “likely”). Finally, the majority of respondents with Bachelor degrees divided themselves between “somewhat likely” (~29%) and “very likely” (37.5%). This educational group also expressed the highest level of uncertainty on the matter, making up ~67% of those that did not know.

24.5.6. Controversies associated with genetically modified (GM) crops among the East African public

Issues that were considered most likely to inspire controversy among the East African public were “potential health concerns”, “potential environmental effects” and “loss of Farmers’ Rights & decision-making fall under control of the biotech companies” (Table 24.14). When the response categories “not likely” and “somewhat likely” were collapsed, the issues considered least likely to inspire controversy were “damaged relationships to neighbouring countries”, that “what is claimed to be achieved through GM can be achieved via conventional means” and “religious and cultural implications” (Table 24.14).

Table 24.14. Likelihood of varius issues inspiring controversy about genetically modified (GM) crops among the East African public, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not likely	Somewhat likely	Likely	Very likely	No answer
Potential health concerns	6.4 [5]	14.1 [11]	29.5 [23]	48.7 [38]	1.3 [1]
Potential environmental effects	5.1 [4]	11.5 [9]	43.6 [34]	38.5 [30]	1.3 [1]
Loss of Farmers’ rights and decision-making fall under control of the biotech companies	14.1 [11]	24.4 [19]	37.2 [29]	24.4 [19]	-
What is claimed to be achieved through GM can be achieved via conventional means	29.5 [23]	26.9 [21]	24.4 [19]	19.2 [15]	-
Religious and cultural implications[2]	28.2 [22]	35.9 [28]	23.1 [18]	12.8 [10]	-
Damagedrelationships to the EU or other Great Powers	24.4 [19]	21.8 [17]	38.5 [30]	14.1 [11]	1.3 [1]
Loss of market (e.g. to the	16.7 [13]	28.2 [22]	41.0 [32]	11.5 [9]	2.6 [2]

EU)					
Damaged relationships to neighbouring countries	30.8 [24]	34.6 [27]	26.9 [21]	7.7 [6]	-

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2] Exemplified in the questionnaire as "'man playing god', sourcing genes from 'unclean' species; negative effects on highly valued cultural crops".

All of the suggested measures for correcting some of the most common misconceptions about GM crops were considered important by stakeholders, but particularly "awareness campaigns" and "more factual and objective media coverage" (Table 24.15).

Table 24.15. Likelihood of various measures in correcting misconceptions about genetically modified organisms (GMOs) in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not likely	Somewhat likely	Likely	Very likely	No answer
Awareness campaigns	5.1 [4]	2.6 [2]	17.9 [14]	71.8 [56]	2.6 [2]
More factual and objective media coverage	3.8 [3]	3.8 [3]	19.2 [15]	70.5 [55]	2.6 [2]
Stronger and clearer guidelines from the government	5.1 [4]	5.1 [4]	23.1 [18]	64.1 [50]	2.6 [2]
Stronger voice of the scientific community	9.0 [7]	9.0 [7]	19.2 [15]	59.0 [46]	3.8 [3]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

24.5.7. Perceived governmental attitude changes towards genetically modified (GM) crops in East Africa

70.5% of stakeholders believed that the government had become "more favourable" towards GM crops over the last few years, while 15.4% believed there had been an attitude change in "less favour" of GM crops (Fig. 24.30). Additionally, 2.6% perceived the government as having become "more and less favourable", while 2.6% believed there had neither been an attitude change towards the positive nor negative (the two latter response alternatives were not part of the original questionnaire, but added by participants) (Fig. 24.30). Finally, 9.0% responded "do not know" (Fig. 24.30).

There were no significant differences in the perceived governmental attitude change on the basis of nationality (Appendices 1, Table E.4). Of those that perceived the governmental attitude change as having become "more favourable", 31 were Kenyan (~56%), nine were Ugandan (~16%), eight were Ethiopian (~15%) and seven were Tanzanian (~13%) (Fig. 24.30). Of those that perceived the attitude of governments as having become "less favourable", nine were Kenyan (75%), one was Ugandan (~8%), one was Tanzanian (~8%) and one was Ethiopian (~8%). The four respondents that considered the governments as having become "more and less favourable" [2] and "neither more nor less favourable” [2] were all of Kenyan nationality. Of those that replied “do not know”, five were Kenyan (~71%), one was Ugandan (~14%) and one was Tanzanian (~14%) (Fig.24.30). Of the seven stakeholders that responded “do not know”, five were Kenyan, one was Ugandan and one was Tanzanian (Fig.24.30).

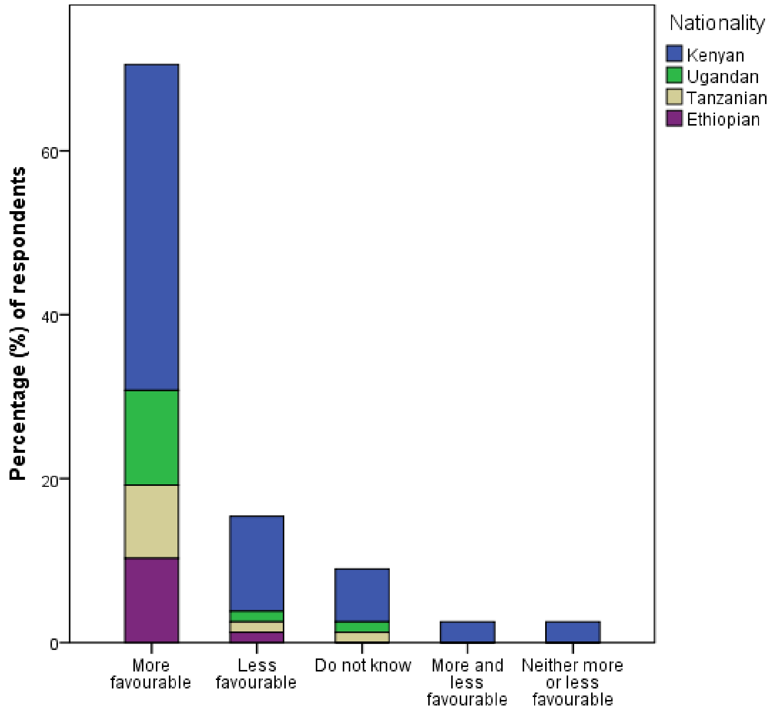


Figure 24.30. Recent governmental attitude change towards genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the perceived governmental attitude change on the basis of nationality (p>0.05). Response rate: 100% (78 out of 78 participants).

As opposed to most questions raised thus far, there were no significant differences in stakeholder perceptions on the basis of perception group or occupation (Appendices 1, Table E.4; Fig. E.5.11.1a+b). However, there were weak, significant differences on the basis of educational level (Appendices 1, Table E.4.). The majority of stakeholders across educational levels perceived the attitude change as having become “more favourable”, particularly those with Masters (~73%) and PhDs (~86%) (Appendices 1, Fig. E.5.11.2).

Possible explanatory factors for governmental attitude changes towards genetically modified (GM) crops

Of the respondents that believed there had been a governmental attitude change towards the positive, the "prospect of climate change" and "positive results from GM-adopting countries" was considered the most likely explanations for this attitude change, while "pressure from pro-GM advocates" and "consumer and farmer demand" was considered the least likely explanations (Table 24.16). Of those that believed the government had become less favourable towards GMOs, "genuine concerns and fear of potential health effects", "pressure from anti-GMO groups" and "fear of losing market access and due to political economy" were deemed the most likely explanations for such an attitude change (Table 24.16). "The technology and approval process is considered too expensive", "fear of politicians losing votes in the next election" and that "GM crops are not really perceived as beneficial" were considered less likely explanations.

Table 24.16. Likelihood of possible causative factors of apparent positive and negative governmental attitude changes toward genetically modified (GM) crops in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

Positive governmental attitude change (more favourable towards GM crops):					
	Not likely	**Somewhat likely**	**Likely**	**Very likely**	**Do not know**
Prospect of climate change	14.7 [10]	16.2 [11]	23.5 [16]	44.1 [30]	1.5 [1]
Positive results obtained from GM-adopting countries	10.3 [7]	14.7 [10]	33.8 [23]	39.7 [27]	1.5 [1]
Pressure from the scientific community	10.1 [7]	30.4 [21]	27.5 [19]	30.0 [20]	2.9 [2]
Consumer and farmer demand	22.4 [15]	15.0 [10]	37.3 [25]	23.8 [16]	1.5 [1]
Pressure from pro-GM advocates	27.9 [19]	20.6 [14]	26.5 [18]	20.6 [14]	4.4 [3]
Negative governmental attitude change towards GMOs (less favourable towards GM crops):					
Genuine concerns and fear of potential health effects	5.1 [3]	28.8 [17]	23.7 [14]	39.0 [23]	3.4 [2]
Pressure from anti-GMO groups	12.1 [7]	24.1 [14]	19.0 [11]	36.2 [20]	8.6 [5]
Fear of losing market access and due to political economy	11.9 [7]	23.7 [14]	28.8 [17]	33.9 [20]	1.7 [1]
Genuine concerns and fear of potential environmental effects	6.8 [4]	23.7 [14]	33.9 [20]	32.2 [19]	3.4 [2]
Fear of socio-economic and socio-political implications	13.8 [8]	22.4 [13]	31.0 [18]	29.3 [17]	3.4 [2]

Inadequate farmer and public demand	19.0 [11]	22.4 [13]	31.0 [18]	24.1 [14]	3.4 [2]
Do not really perceive GM crops as beneficial	25.9 [15]	29.3 [17]	19.0 [11]	24.1 [14]	1.7 [1]
Fear of politicians losing votes in the next election	39.0 [23]	15.3 [9]	16.9 [10]	22.0 [13]	6.8 [4]
The technology and approval process is considered too expensive	32.2 [19]	18.6 [11]	23.7 [14]	18.6 [11]	6.8 [4]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
Note: The observed number of respondents often exceeded the expected number, i.e. 55 and 16 for those that believed the government had become more and less favourable towards GM crops, respectively (alternatively including the number of respondents that found the attitude change "more and less favourable" [2]).

24.5.8. Perceived public attitude changes towards genetically modified (GM) crops in East Africa

51.3**%** of stakeholders believed that the "public had become more favourable towards GMOs in recent years", 32.1% found the opposite to be true, while 15.4% did not have an opinion (1.3% did not respond; not shown in Fig. 24.31 (Fig. 24.31). There were no significant differences in the perceived public attitude change on the basis of nationality (Appendices 1, Table E.4). Of those that perceived the public as having become "more favourable", 27 were Kenyan (~67%), six were Ugandan (~15%), five were Ethiopian (~13%) and two were Tanzanian (~5%) (Fig. 24.31). Of those that perceived the public as having become "less favourable", 15 were Kenyan (60%), four were Ugandan (16%), three were Tanzanian (12%) and three were Ethiopian (12%). Additionally, 12 participants did not have an opinion, of whom six were Kenyan (50%), four were Tanzanian (~33%), one was Ugandan (~8%) and one was Ethiopian (~8%). One participant (Kenyan) did not reply (not shown in Fig. 24.31).

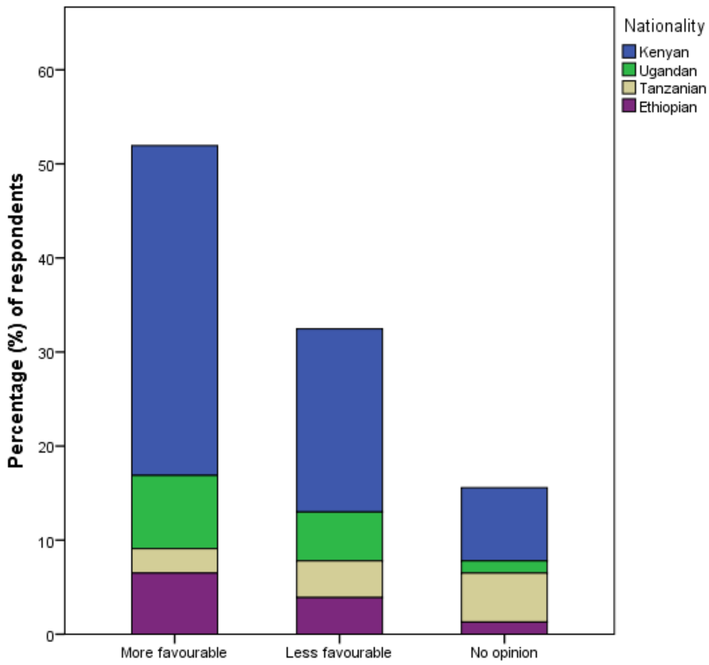


Figure 24.31. Recent public attitude change towards genetically modified organisms (GMOs) in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, and a media representative. There were NS differences in the perceived public attitude change on the basis of nationality (p>0.05). Response rate: ~99% (77 out of 78 participants).

However, there were significant differences in the perceived public attitude change on the basis of the respondents' perception group (Appendices 1, Table E.4). 80% of the respondents that belonged to PG4 believed there had been an attitude change in favour of GM crops (thus making up ~70% of the respective response category) (Appendices 1, Fig. E.5.10a). None of the stakeholders from PG1 believed there had been a public attitude change towards the positive, while this perception group constituted ~48% of those that believed there had been an attitude change in less favour of GM crops among the public (the remaining respondents did not have an opinion) (Appendices 1, Fig. E.5.10a). Additionally, there were weakly significant differences in the perceived public attitude change on the basis of occupational group (Appendices 1, Table E.4). The majority of extensions workers (~78%), civil servants employed in the public/private sector related to agriculture (65%) and agricultural researchers (~57%) perceived the attitude change as having been in favour of GM crops, while the majority of those employed in an NGO (~56%) was of the opposite opinion (~31% believed there had been an attitude change towards the positive, while ~13% did not have an opinion) (Appendices 1, Fig. E.5.10b).

24.5.9. Likelihood of commercialisation

5.3% of stakeholders found it “not likely” that their country would “approve the commercialisation of GM crops within the next few years”, while 21.1% found it “somewhat likely”, 25.0% “likely” and 32.9% “very likely” (Fig. 24.32). 14.5% replied that their country had “already approved GM crops” (1.3% did not respond; not shown in Fig. 24.32) (Fig. 24.32).

There were no significant differences in the perceived likelihood of commercialisation on the basis of nationality (Appendices 1, Table E.4). Of those that found it “not likely”, two were Kenyan (50%), one was Ugandan (25%) and one was Tanzanian (25%) (Fig. 24.32). Of those that perceived it as “somewhat likely”, 12 were Kenyan (75%), two were Tanzanian (~13%), one was Ugandan (~6%) and one was Ethiopian (~6%). Of the stakeholders that perceived commercialisation as “likely”, eight were Kenyan (~42%), five were Ugandan (~26%), four were Tanzanian (~21%) and two were Ethiopian (~11%). Of the respondents that found it “very likely”, 15 were Kenyan (60%), six were Ethiopian (24%), three were Ugandan (12%) and one was Tanzanian (4%). All of the 11 stakeholders that responded that their government had already approved commercialisation were Kenyan (Fig. 24.32).

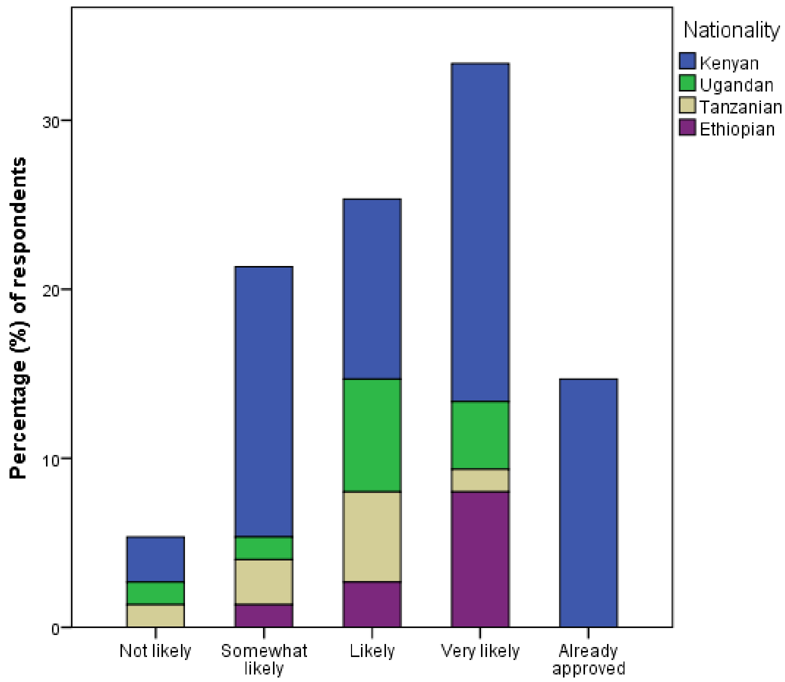


Figure 24.32. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that perceived it as likely that genetically modified (GM) crops would become commercialised in their country within the next few years. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the perceived likelihood of commercialisation on the basis of nationality ($p>0.05$). Response rate: ~96% (75 out of 78 participants).

However, there were significant differences in the perceived likelihood of commercialisation on the basis of perception group (Appendices 1, Table E.4). For instance, the majority of respondents from PG4 perceived commercialisation as “very likely” (~47%) or as having “already been approved”

(~29%) (none from PG4 found it "not likely"), while stakeholders from PG1 spread relatively evenly across response categories (though the fewest number of respondents considered it "not likely") (Appendices 1, Fig. E.5.12).

24.5.10. Barriers to, and measures to allow for, adoption of genetically modified (GM) crops in East Africa

Barriers to the adoption of genetically modified (GM) crops

All barriers, with the exception of "concerns of damaging relationships with non-GM adopting neighbouring countries", were considered "very important" by the majority of stakeholders (Table 24.17). However, when the response categories "not important" and "somewhat important", and "important" and "very important", were collapsed, then "misinformation and misperception among the public and farmers", "lobbying by anti-GM advocates", "consumer distrust" and "lack of political will" came across as the most important barriers to GM crop adoption in East Africa (Table 24.17). Contrary, "concerns of damaging relationships with non-GM adopting neighbouring countries", "concerns of damaging relationships with the EU" and "inadequate donor funding" were considered of less importance (Table 24.17).

Table 24.17. Level of Importance of various barriers to the adoption of genetically modified (GM) crops in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not important	Somewhat important	Important	Very important	I do not know/no answer
Misinformation and misperception among public and farmers	3.8 [3]	5.1 [4]	21.8 [17]	60.3 [47]	9.0 [7]
Consumer distrust	2.6 [2]	14.1 [11]	24.4 [19]	52.6 [41]	6.4 [5]
Lack of political will	9.0 [7]	7.7 [6]	25.6 [20]	51.3 [40]	6.4 [5]
Lobbying by anti-GM advocates	7.7 [6]	7.7 [6]	29.5 [23]	50.0 [39]	5.2 [4]
Lack of technical, human and infrastructural capacity	12.8 [10]	11.5 [9]	25.6 [20]	47.4 [37]	2.6 [2]
Weak public/farmer demands and reluctance	7.7 [6]	17.9 [14]	24.4 [19]	42.3 [33]	7.7 [6]
Polarised debate presented in the media	6.4 [5]	16.7 [13]	29.5 [23]	42.3 [33]	5.1 [4]
Inadequate donor funding	16.7 [13]	12.8 [10]	17.9 [14]	42.3 [33]	10.2 [8]
Weak, inefficient, contradictory attitudes of regulatory bodies	7.7 [6]	15.4 [12]	32.1 [25]	41.0 [32]	3.9 [3]
Trade concerns and loss of market access	7.7 [6]	23.1 [18]	24.4 [19]	41.0 [32]	3.9 [3]
Concerns of damaging relationships with the EU	11.5 [9]	23.1 [18]	19.2 [15]	38.5 [30]	7.7 [6]

Concerns of damaging relationships with non-GM adopting neighbouring countries	24.4 [19]	21.8 [17]	28.2 [22]	20.5 [16]	5.1 [4]

[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.

Measures to allow for the successful adoption of genetically modified (GM) crops

As with the barriers above, the majority of respondents found all suggested measures for facilitating the successful adoption of GM crops "very important" (Table 24.18). When categories were collapsed (as described above), the most important measures were identified as being "increased awareness of farmers and the public; farmer and public demand", "increased political will", "increased human and infrastructural capacity", "capacity building programs & public-private partnerships" and "supporting research in the domestic public as opposed to private multinationals" (Table 24.18). Both less and increased "interference from the international community", "royalty free seeds" and "opening up trade barriers" were perceived as the least important measures (Table 24.18).

Table 24.18. Level of importance of various measures for the successful adoption of genetically modified (GM) crops in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1]; in % and [number] of total respondents [78].

	Not important	Somewhat important	Important	Very important	I do not know/no answer
Increased awareness of farmers and the public; farmer and public demand	2.6 [2]	1.3 [1]	9.0 [7]	84.6 [66]	2.6 [2]
Increased political will	3.8 [3]	5.1 [4]	15.4 [12]	73.1 [57]	2.6 [2]
Supporting research in the domestic public as opposed to private multinationals	5.1 [4]	5.1 [4]	19.2 [15]	70.5 [55]	-
Capacity building programs; public-private partnerships	5.1 [4]	3.8 [3]	17.9 [14]	70.5 [55]	2.6 [2]
Increased human and infrastructural capacity	3.8 [3]	7.7 [6]	14.1 [11]	70.5 [55]	2.6 [2]
Objective and factual media coverage	1.3 [1]	2.6 [2]	23.1 [18]	67.9 [53]	5.1 [4]
Science-based regulatory systems	1.3 [1]	6.4 [5]	19.2 [15]	67.9 [53]	5.1 [4]
Non-polarised	6.4 [5]	10.3 [8]	26.9 [21]	51.3 [40]	5.1 [4]

debate among pro- and anti-GM advocates					
Royalty-free seeds	12.8 [10]	11.5 [9]	20.5 [16]	46.2 [36]	9.0 [7]
Opening up trade barriers	9.0 [7]	9.0 [7]	28.2 [22]	43.6 [34]	9.2 [8]
Less interference from international community	7.7 [6]	19.2 [15]	33.3 [26]	38.5 [30]	1.3 [1]
Increased interference from international community	26.9 [21]	17.9 [14]	21.8 [17]	28.2 [22]	5.1 [4]
[1] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.					

24.5.11. Consumption and labelling

Previous consumption of genetically modified (GM) food products

46.2% of stakeholders were not aware whether they had consumed GM food items, 43.6% reported that they had, while 10.3% said they had not consumed food products with GM content (Fig.24.33). There were no significant differences in terms of whether participants had consumed GM food products on the basis of nationality (Appendices 1, Table E.4). Of the stakeholders that had consumed GM food items, 20 were Kenyan (~59%), seven were Ethiopian (~20%), four were Ugandan (~12%) and three were Tanzanian (~9%) (Fig.24.33). Of those that had not consumed such products, six were Kenyan (75%), one was Tanzanian (12.5%) and one was Ethiopian (12.5%). Of the 36 respondents that replied “do not know”, 23 were Kenyan (~64%), seven were Ugandan (~19%), five were Tanzanian (~14%) and one was Ethiopian (~3%) (Fig.24.33).

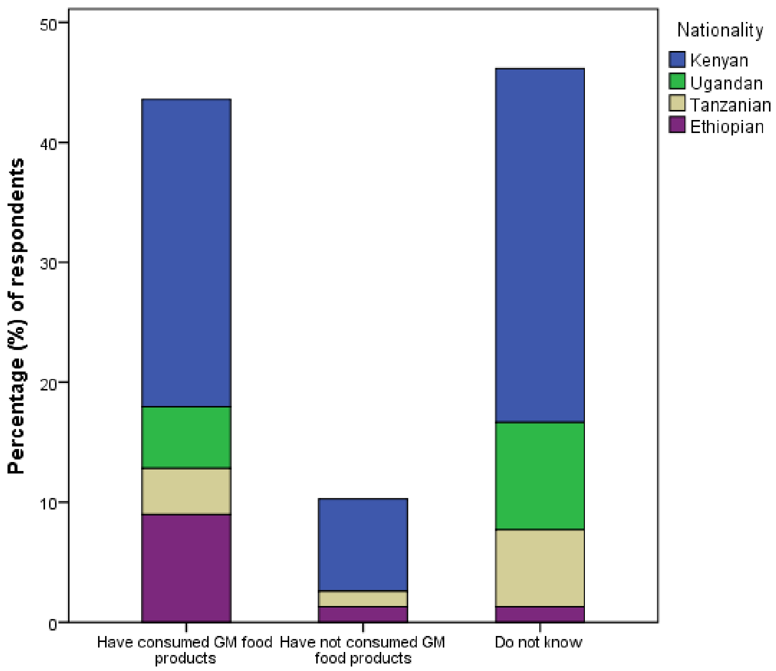


Figure 24.33. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that had consumed genetically modified (GM) food products. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in whether stakeholders had consumed GM food products on the basis of nationality ($p>0.05$). Response rate: 100% (78 out of 78 participants).

There were weakly significant differences in whether stakeholders had consumed GM food products on the basis of perception group (Appendices 1, Table E.4). The majority (~63%) of respondent from PG4 stated that they had previously consumed such food products, and this perception group further made up ~65% of the respective response category (Appendices 1, Table E.5.13). The majority of respondents from PG1 and PG3 were unsure whether they had consumed such products, while stakeholders of PG2 divided themselves equally between “yes” and “do not know” (Appendices 1, Table E.5.13).

Additionally, there were significant differences in whether participants had consumed GM food products on the basis of educational level (Appendices 1, Table E.4). ~86% of those with PhD level education said they had eaten such commodities, while none responded that they had not (Appendices 1, Fig. E.5.13.1a). Contrary, none of those with secondary level education had consumed GM food items (Appendices 1, Fig. E.5.13.1a). The majority of those with Bachelor degrees divided themselves equally between “have consumed GM food products” (~42%) and “do not know” (~42%) (~17% had not consumed such products), while the majority (~54%) of respondents with Masters remained unsure (~38% had consumed, while ~8% had not) (Appendices 1, Fig. E.5.13.1a).

Furthermore, there were significant differences on the basis of family background (Appendices 1, Table E.4). The majority of participants growing up in a non-farm family had consumed GM food products (~73%), compared to 37% of those with a farm family background (Appendices 1, Fig.

E.5.13.1b). Additionally, ~52% of those with a farm family background did not know whether they had eaten GM foods compared to 20% of those with a non-farm family background (Appendices 1, Fig. E.5.13.1b).

Willingness-to-consume genetically modified (GM) food products

Of those that had not consumed GM food products or were unaware of having done so, 71% were willing to consume, while 29% were not (Fig. 24.34). There were no significant differences in the willingness to consume on the basis of nationality (Appendices 1, Table E.4). Of the participants that would eat GM food products, 17 were Kenyan (~77%), three were Ugandan (~14%) and two were Tanzanian (~9%) (Fig. 24.34). Of those not willing to consume such food items, four were Kenyan (~44%), three were Tanzanian (~33%), one was Ugandan (~11%) and one was Ethiopian (~11%). As the question presupposed that participants were unsure of or had not consumed GMO products in the past, a large number of participants did not submit a response, of which 28 were Kenyan (~60%), eight were Ethiopian (~17%), seven were Ugandan (~15%) and four were Tanzanian (~9%) (Fig. 24.34).

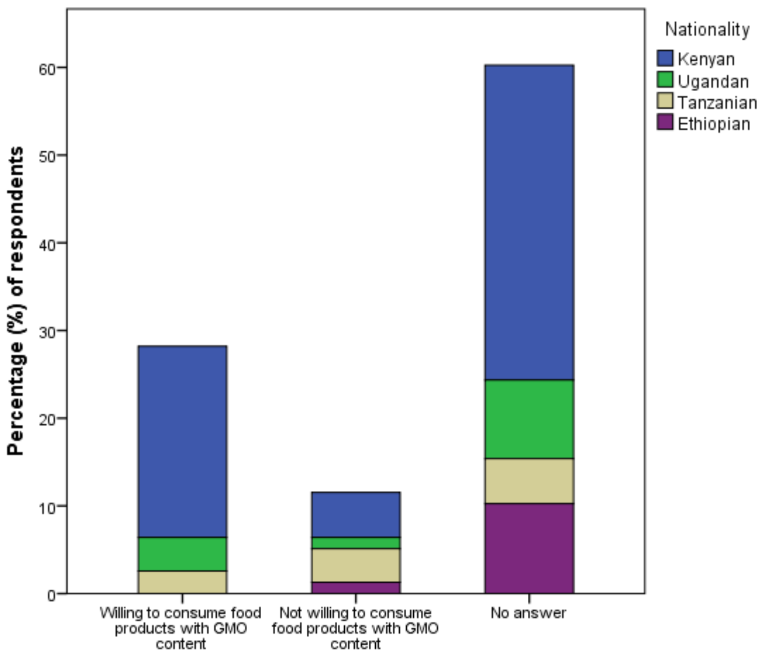


Figure 24.34. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that was willing to consume food products with content from a genetically modified organism (GMO). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the willingness to consume on the basis of nationality ($p>0.05$). Response rate: ~40% (31 out of 78 participants). Note that the low response rate was because the question was meant to presuppose that participants were unsure of or had not consumed GMO products in the past.

The only demographic for significant effect was found was for perception group (Appendices 1, Table E.4). Those that were not willing to consume food products with GMO content consisted entirely of participants from PG1 or PG2, though ~33% and 50% of the respondents from the respective perception groups were willing to consume GM food products, (Appendices 1, Table E.5.13; Fig. E.5.13.2).

Labelling

64.1% of stakeholders said they paid attention to labels for food products (35.9% did not), whereby 38.5% also checked whether it had GMO content (50.8% did not) (Fig. 24.35a+b). There were no significant differences in terms of whether participants paid attention to food labels or checked for GMO content on the basis of nationality (Appendices 1, Table E.4).

Of those that paid attention to food labels, 31 were Kenyan (62%), eight were Tanzanian (16%), six were Ugandan (12%) and five were Ethiopian (10%). Of those that did not pay attention to food labels, 18 were Kenyan (~64%), five were Ugandan (~18%), four were Ethiopian (~14%) and one was Tanzanian (~4%). Of those that also checked for GMO content, 18 were Kenyan (60%), six were Tanzanian (20%), three were Ugandan (10%) and three were Ethiopian (10%). Of the stakeholders that did not check for GMO content, 21 were Kenyan (~68%), four were Ugandan (~13%), four were Ethiopian (~13%) and two were Tanzanian (~6%). As the latter inquiry was meant to presuppose that respondents paid attention to food labels, a number of stakeholders fell within the "no answer" category. Of these, 10 were Kenyan (~59%), four were Ugandan (~24%), two were Ethiopian (~6%) and one was Tanzanian (~6%).

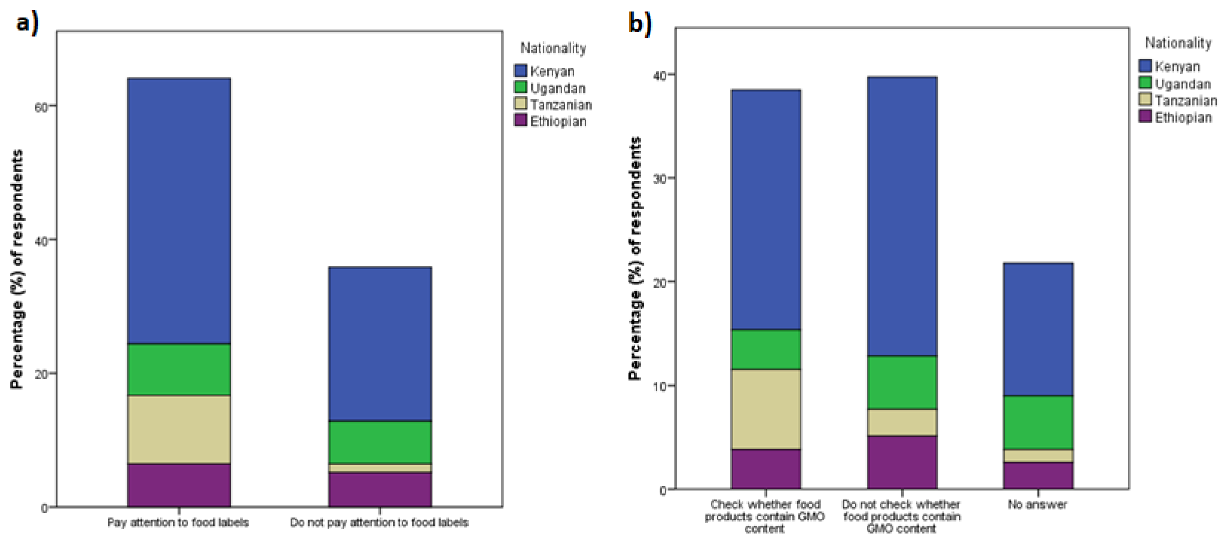


Figure 24.35. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that a) paid attention to food labels and b) checked whether it contained content from a genetically modified organism (GMO). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were NS differences in whether participants paid attention to food labels on the basis of nationality ($p>0.05$). Response rate: 100% (78 out of 78 participants). **b)** There were NS differences in whether participants checked for GMO content on the basis of nationality ($p>0.05$). Response rate: ~78% (61 out of 78 participants). Note that the relatively low response rate was because the question was meant to presuppose that participants paid attention to food labels.

There were significant differences in whether participants paid attention to food labels and checked for GMO content on the basis of perception group (Appendices 1, Table E.4). For the former, ~94% and 75% of respondents from PG1 and PG2 paid attention to food labels, while respondents PG3 and PG4 spread relatively equally across those that did and those that did not check for food labels (Appendices 1, Table E.5.13). In the case of checking for GMO content, all of those from PG2 and ~82% of respondents from PG1 checked whether the food item had GMO content, while ~67% and ~72% of respondents from PG3 and PG4 did not check (Appendices 1, Table E.5.13).

Additionally, there were significant differences in whether participants paid attention to food labels on the basis of the respondents' sex (Appendices 1, Table E.4). ~87% of female respondents paid attention to labels compared to ~55% of male participants (Appendices 1, Fig. E.5.13.3a). A similar effect was not observed in the case of checking for GMO content (Appendices 1, Table E.4, Fig. E.5.13.3b).

Finally, there were weakly significant differences in whether stakeholders paid attention to food labels on the basis of educational level, while there were strong significant differences in terms of checking for GMO content on the basis of occupation (Appendices 1, Table E.4). For the former, ~71% of those with PhDs did not check labels, while the majority of those with secondary (75%), some college (~67%), Bachelors (75%) and Masters (~69%) did pay attention to food labels (Appendices 1, Fig. E.5.13.4a). In terms of checking for GMO content, ~86% of civil servants from

NGOs checked, while ~67% and ~71% of agricultural researchers and civil servant employed in the public/private sector related to agriculture did not, respectively (extension workers divided themselves relatively equally between response categories) (Appendices, Fig. E.5.13.4b).

Level of support for strict regulations and labelling

75.6% of stakeholders supported strict regulations and labeling of food products, while 23.1% did not (1.3% did not respond; now shown in Fig. 24.36) (Fig. 24.36). There were no significant differences in the opinions of regulations and labelling on the basis of nationality (Appendices 1, Table E.4). Of those that were in support, 38 were Kenyan (~64%), eight were Ugandan (~14%), eight were Tanzanian (~14%) and five were Ethiopian (~8%) (Fig. 24.36). Of the stakeholders that were opposed, ten were Kenyan (~56%), four were Ethiopian (~22%), three were Ugandan (~17%) and one was Tanzanian (~6%) (Fig. 24.36). One participant (Kenyan) did not reply (not shown in Fig. 24.36).

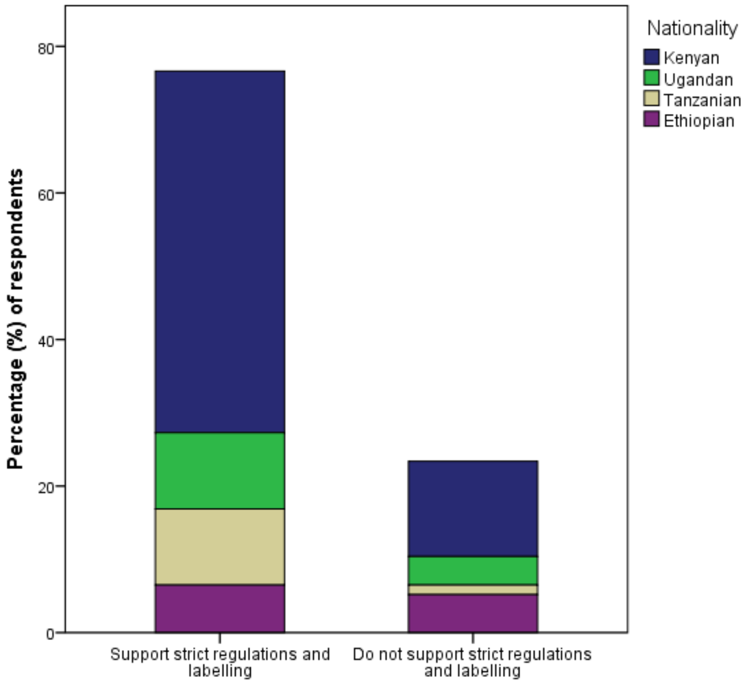


Figure 24.36. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported strict regulations and labelling of food products in their country. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were NS differences in the opinions of regulations and labelling on the basis of nationality (p>0.05). Response rate: ~99 % (77 out of 78 participants).

The only demographic for which significant differences were found were on the basis of educational level (Appendices 1, Table E.4). All of those with secondary, ~89% of those with some college, ~79% of participants with Bachelors and ~88% of those with Masters supported strict regulations and labelling of food products, while ~64% of the respondents with PhDs were opposed to strict regulations and labelling (Appendices 1, Fig. E.5.13.5).

24.5.12. Importation and sale

67.9% of stakeholders supported importation and sale of food products with GMO content in their country, while 30.8% did not (1.3% did not respond; not shown in Fig. 24.37) (Fig. 24.37). There were significant differences in the level of support for importation and sale of GM food products on the basis of nationality (Appendices 1, Table E.4). Of those that supported importation and sale of GMO food products, 34 were Kenyan (~64%), nine were Ethiopian (~17%), seven were Ugandan (~13%) and three were Tanzanian (~6%) (Fig. 24.37). Of the stakeholders that did not support importation and sale, 14 were Kenyan (~58%), six were Tanzanian (25%) and four were Ugandan (~17%). One participant (Kenyan) did not reply (not shown in Fig. 24.37) (Fig. 24.37).

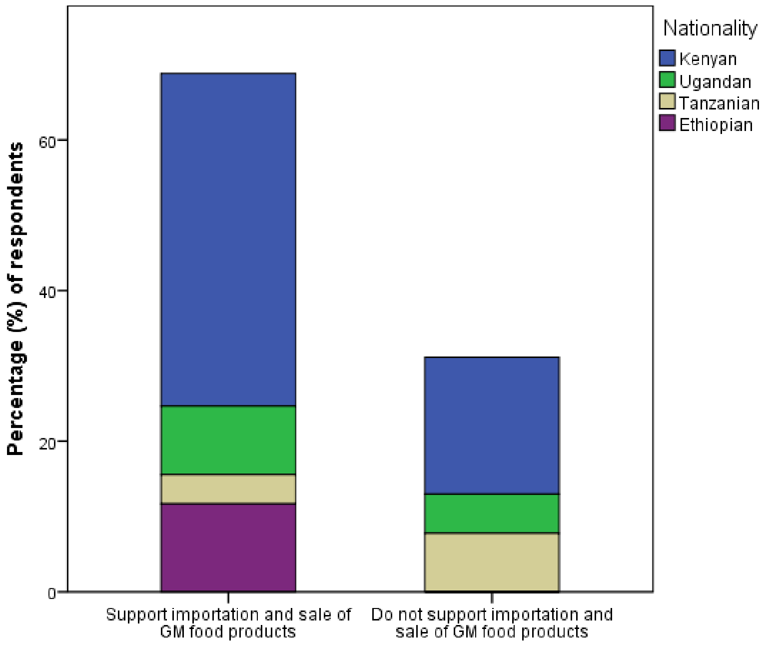


Figure 24.37. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders that supported importation and sale of genetically modified (GM) food products. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the level of support for importation and sale of GM food products on the basis of nationality ($p<0.05$). Response rate: ~99 % (77 out of 78 participants).

Thus, all of the Ethiopian and the majority of Kenyan (~69%) and Ugandan (~64%) stakeholders supported importation and sale, while the majority (~67%) of Tanzanian respondents did not.

Additionally, educational level, occupation, perception group and age group all had significant effects (Appendices 1, Table E.4). All of those with PhDs and secondary education supported importation and sale of GM food products, while respondents with some college, Bachelors and Masters appear to spread relatively evenly across response categories (Appendices 1, Fig. E.5.13.6a). In the case of perception groups, ~74% and 91% of those from PG3 and PG4 supported importation and sale, while ~78% of those from PG1 did not (respondents from PG2 divided themselves equally between the two response categories) (Appendices 1, Fig. E.5.13.6b). In terms of occupation, ~68%, ~73% and 95% of civil servants employed in the public/private sector related to agriculture, extension workers and agricultural researchers supported importation and sale, respectively, while ~65% of the representatives from NGOs did not support importation and sale (the remaining occupational groups spread relatively evenly between “in support” and “not in support”) (Appendices 1, Fig. E.5.13.7a). Finally, the majority of those aged 30-39 (~74%) and 40-49 (~88%) supported importation and sale; those aged 19-29 and 50-59 spread evenly between the two response categories; while a slight majority of those aged 60-69 did not support importation and sale (Appendices 1, Fig. E.5.13.7b).

24.6. Summary and discussion of main findings: Stakeholder survey

24.6.1. Attitudes towards genetically modified (GM) crops and the perceived role of agricultural biotechnology in advancing the agricultural sector

Relatively few studies have investigated the attitudes and opinions of GM crops among stakeholder in Africa. In Ghana, it was found that the majority of leaders from farmer-based organisations were aware and positive towards the use of agricultural biotechnology for improving the country's food security (Zakaria *et al*., 2014). Still, stakeholders expressed concerns associated with potential policy failures, environmental and health-related risks, and loss of markets. In South Africa, a 2000-study found that stakeholders involved in the GMO debate (i.e. from academia, the government, church, NGOs, producer and consumer organisations, and the industry) saw significant potential in genetic engineering of plants in terms of meeting several agronomic issues (e.g. drought, inconsistent yield, and pest and diseases), and that transgenic crops could result in positive economic impacts for small and large-scale farmers (Aerni, 2005). However, seeing as the study was conducted 17 years ago, opinions might have been subject to change. Furthermore, it is important to keep in mind that South Africa stands apart from the rest of Africa in that the country has a relatively well-resourced research community, long practical experience using agricultural biotechnology (for instance, the first field trials and conditional commercial release were approved in 1992 and 1997, respectively), and cultivates large areas of GM crops (Chapter 1) (Aerni, 2005; Cooke & Downie, 2010).

Previously conducted perception studies in East Africa have shown that the majority of Kenyan stakeholders were positive towards GM crops and foods (Njoka *et al*., 2011), while Tanzanian stakeholders have expressed more negative impression of GMOs (United Republic of Tanzania, 2012). However, the recent survey by Mnaranara *et al*. (2017) found that regulatory authorities and academics in Tanzania generally expressed positive attitudes towards GM crops and food, while media representatives exhibited higher levels of concerns.

Somewhat consistent with studies by Aerni (2005), Njoka *et al*. (2011), Zakaria *et al*. (2014) and Mnaranara *et al*. (2017), the majority of stakeholders (70.5%) "agreed" or "strongly agreed" that "GM crops should play a role in addressing issues of food insecurity, hunger and poverty in their country". The support for the commercialisation of GM cash crops (70.5%) was higher than for GM food crops (60.3%), which indicates that the level of acceptance is – at present time – greater when such crops are not meant for direct consumption. This is likely to reflect that the global market is currently being dominated by biotech cash crops (meant for industrial use or animal feed), as well as the strong opposition that exist against GM foods among certain stakeholders (e.g. some anti-GMO NGOs and consumer organisations).

Leading on from this, the majority of stakeholders of the present study expressed some level of agreement that East African countries should fully exploit conventional measures and develop their regulatory/infrastructural capacity before the use of biotechnology and GMOs. This may appear somewhat contradictory seeing as the majority of stakeholders agreed that GM crops should play a role in addressing issues of food insecurity, hunger and poverty. Still, the former (conventional measures and development of regulatory/infrastructural capacity) does not exclude the latter (biotechnology) (or the other way around), but the finding do bear witness of the importance of conventional measures and infrastructural improvements for the agricultural sector in East Africa. This is further supported by the fact that 73% of stakeholders found "lack of technical, human and infrastructural capacity” to be an “important” or “very important barrier” to GM crop adoption (consistent with studies by e.g. Pray & Naseem (2003), Virgin *et al*. (2007) and Ezezika *et al*., (2012); Chapter 21), and further identified “increased human and infrastructural capacity” as an important measure to allow for the successful adoption of biotech crops (Table 24.18).

24.6.2. Concerns, controversies and socio-economic implications associated with genetically modified (GM) crops

Potential environmental, ecological and health effects. The most pressing concerns associated with GM crops were potential “environmental effects” and “development of resistance by pest and pathogens”, which is consistent with what is discussed in Chapter 5, as well as studies by e.g. Aerni (2005), Kimenju & De Groote (2008), Bett *et al*. (2010), United Republic of Tanzania (2012), Zakaria *et al*. (2014) and Mnaranara *et al*. (2017). Aerni (2005) found that stakeholders had doubts about the sustainability of Bt crops due to development of resistance by pests. Additionally, potential environmental and health concerns were among the issues perceived most likely to inspire controversy among the public (Table 24.14), as well as give rise to negative attitudes towards GM crops among governments (Table 24.16).

Trade and market concerns. Consistent with the amount of attention that proposed trade and market effects have received in the GMO debate in Africa (Chapter 19), “damaged relationship and loss of trade with EU” was considered one of the most serious concerns by stakeholder (consistent with e.g. Kagai, 2011) (Table 24.12), while “trade concerns” and issues related to “market access and political economy” were believed to inspire controversy among the public (Table 24.14), cause a political attitude change towards the negative (Table 24.16), and work as a barrier to GM crop adoption (Table 24.17). This is despite that fact that most studies have shown that trade-related concerns are largely unfound (e.g. Anderson & Jackson, 2005; Paarlberg, 2006; Minde & Mazvimavi, 2007; Gruère & Sengupta, 2009; Komen & Wafula, 2013; Chapter 19).

Socio-economic concerns associated with GM crop adoption. The majority of stakeholders were “not” or only “somewhat concerned” about “socio-economic reasons” and “altered social structure” as a result of GM crop adoption (“widening income gaps” was used to exemplify the former, while the latter was exemplified with “altered patterns of relationships between different groups, e.g. men are benefiting more than women and hence causing gender inequality”; other examples which were not included in the questionnaire may relate to altered power relations between e.g. old and young, rich and poor, healthy and handicapped/diseased, single and married, and so forth) (Table 24.13).

In terms of specific potential socio-economic changes, “local smallholder Farmers’ Rights being negatively affected”, “increased income gap between rich and poor farmers” and “concentration of power and capital in commercial farms” were all considered to some degree likely (though the response alternative with the highest number of respondents was “not likely”). The exception was “women being negatively affected (gender inequality)”, for which the majority considered “not likely”.

The above-mentioned findings are interesting in terms of what has previously been discussed on the matter of socio-economic considerations. It appears as if socio-economic and social concerns are present and valid among East African stakeholders, and issues related to Farmers’ Rights (Chapter 13) and equal distribution of benefits among small and larger-scale and commercial farm (Chapter 16) are important considerations. However, as with the perceived potential trade implications, what *do* exist in the literature appears to have relatively minor effect on the perceptions of stakeholders. For instance, despite the seemingly large amount of studies indicating that small-scale farmers can be among the biggest beneficiaries of GM crops (Chapter 16), respondents still found it likely that the income gap between rich and poor farmers would increase. Contrary, the majority of participants did not believe that women would be negatively affected, despite there being a comparably smaller body of literature on the topic, while indications from studies on the impact of the Green Revolution have shown that women often are the ones losing out (Chapter 22).

24.6.3. Perceived governmental & public attitude changes, and the prospect of commercialisation

Governmental attitude changes. The majority of all stakeholders across nationalities (70.5%) perceived governmental attitude changes as having been in favour of GM crops in latter years, which is consistent with the recent regulatory amendments and increased political will expressed by Ethiopian and Tanzanian governments (Chapter 7). The fact that the majority of Ugandan participants found the attitude change to have been towards the positive might be a result of the country's long tradition for R&D, and could possibly indicate that the Biotechnology and Biosafety Bill will be passed into law in the foreseeable future (despite some internal political conflict) (Chapter 7). In the case of Kenyan stakeholders, a relatively large number of participants perceived the attitude change to have been towards the negative, while some "did not know" or considered the attitude change as having been "more and less favourable" and "neither more nor less favourable" (Fig. 24.30). This finding could reflect the somewhat contradictory attitudes of regulatory bodies and difficult-to-navigate political climate surrounding GM crops in the country (Chapter 7).

The most likely explanations for an apparent governmental attitude change in favour of GM crops were considered to be due to "the prospect of climate change" (Chapter 3, section 3.2) and "positive results obtained from GM-adopting countries" (Chapter 16, section 16.1) (Table 24.16). Contrary to what was suggested by Dr. Oduor (Chapter 7, section 7.3.1.3), the majority of stakeholders did not consider "fear of politicians losing votes in the next election" as among the most likely explanations for an apparent negative attitude change. Still, as seen in the demonstration by Ugandan farmers (Chapter 7, section 7.3.2.2), the GMO debate certainly has the potential of upsetting voters. Additionally, that "GM crops are not really perceived as beneficial" and that "the technology and approval process is considered too expensive" (Chapter 20), were not considered particularly likely to encourage negative attitudes among governments (Table 24.16). Instead, "genuine concerns and fear of potential health effects" (Chapter 5) and "pressure from anti-GMO groups" (Chapter 9) were considered the most likely explanations for negative attitudes changes (Table 24.16).

Public attitude changes. Interestingly, in terms of the public attitude change, just little over half of the stakeholders (51.3%) perceived it as having become more favourable towards GM crops. That being said, stakeholders appeared to express a high level of uncertainty on this matter, i.e. 18.7% said they did not know, thus leaving 32.1% of stakeholder to believe there had been an attitude change towards the negative. Potential negative public attitudes might be explained by the many controversies that characterise the GMO debate (Table 24.14) and/or factors such as mistrust towards governments, regulatoryinstitutions, biotech companies, and so forth. Additionally, the level of uncertainty may reflect the difficulty in assessing public attitudes compared to governmental ones (for the latter, statements or policy changes serve as good indicators), especially in a country in which the advent of the technology is still at its infancy and as a result has not achieved as much public ground and attention (e.g. Tanzania and Ethiopia).

Likelihood of commercialisation. Leading on from this, 57.9% of stakeholders believed it was “likely” or “very likely” that GM crops would become commercialised within the next few years, whereas only 5.3% found it “not likely at all”. Such opinions are likely to reflect the perceived governmental and public attitude changes towards GM crops. Thus, according to the results from this study, it appears likely that commercialised events will hit the East African market in a few years’ time. In fact, eleven Kenyan stakeholders said their country had “already approved” GM crops, which referred to the recent authorisation of environmental release of Bt-WEMA-maize and Bt cotton (Chapter 7, section 7.3.1.4).

24.6.4. Important barriers to, and measures for, the successful adoption of genetically modified (GM) crops

Stakeholders identified “misinformation and misperception among the public and farmers”, “consumer distrust”, “lack of political will” and “lobbying by anti-GM advocates” as the most important barriers to GM crop adoption in East Africa (Table 24.17). Some of these findings are consistent with James (2015) who identified “active, vocal and strong anti-GMO organisations” and a “misinformed public” as obstacles for transgenic research and biotech adoption in certain East African countries.

Consequently, “increased awareness of farmers and the public; farmer and public demand” was considered the most important measure to allow for the successful adoption of GM crops (Table 24.18). This finding further emphasise on the need of including farmers and the public in the debate on, and the development and dissemination of, GM crops. In this respect, it can be important to implement various measures for correcting some common misconceptions about biotech crops, including “awareness campaigns” and “more factual and objective media coverage” (Table 24.15). Currently, efforts to educate and raise awareness are being carried out by, amongst others, the African Biotechnology Stakeholder Forum (ABFS), COSTECH, ISAAA, OFAB and UBIC. Awareness-raising often include various communication strategies such as workshops, open meetings/forums, knowledge-sharing events, scientists-journalists pairing programs, seeing-is-believing tours, and various publications. However, as argued by some authors (e.g. Schnurr & Mujabi-Mujuz, 2014), certain awareness measures appear to first-and-foremost be aimed at the farmer elite, which underlines the need of far-reaching efforts in order to engage the rural poor and marginalised groups (e.g. women and the elderly).

Additionally, “supporting research in the domestic public as opposed to private multinationals” and “capacity building programs; public-private partnerships” were both considered essential in allowing for the successful implementation of GM crops (also evident in Chapter 8, Table 8.1), which is a testament of the importance of engaging both the international and local public and private sector. Still, as discussed in Chapter 20, there is room for improvement when designing and executing PPPs and donor projects. For instance, 60.2% of stakeholders considered “inadequate donor funding” as an “important” or “very important” barrier to biotech crop adoption. Also, 66.7% of stakeholders considered “royalty-free seeds” as an “important” or “very important” measure for the successful adoption of biotech crops. However, some stakeholders raised the concern that “free” seeds may create misconceptions that GM crops are reserved for the poor, which ultimately could lead to farmer and consumer reluctance.

Finally, as discussed in Chapter 7, stakeholders underlined the importance of "science-based regulatory systems" and "increased political will" for the successful implementation of biotech crops (Table 24.18).

24.6.5. Consumption, labelling, importation and sale of food products with genetically modified (GM) content

The majority of stakeholders (46.2%) were unaware whether they had consumed food items with GMO content – though many considered it highly probable (evident from additional comments made by the participants) – while only 10.3% remained certain that they had not. Of those that were unsure or had not consumed food products with GMO content, 71% were willing to eat such products.

The majority of stakeholders (64.1%) paid attention to food labels, but most did not check whether it had GM content or not (50.8%). This appear somewhat consistent with the study by Botha & Viljoen (2009) which found that South African consumers did not pay attention to GM food labelling, despite the country's mandatory labelling law. However, mandatory labelling has yet to be established in some of the study countries, thus rendering it unnecessary to check for GMO content. Still, the majority of stakeholders (75.6%) supported strict regulation and labelling of food products (note that the question was not framed to explicitly concern food products with GMO content, though it is natural to assume that the question was interpreted this way). Thus, despite the many pros and cons of labelling (Chapter 15), labelling requirements appear to be important for East African stakeholders, including many farmers which valued labels as a way of avoiding counterfeiting and building trust (data collection team, pers. comm.). Still, it could prove beneficial to ensure that labelling requirements are compatible with roadside and open air markets, and/or to ease down on particularly strict penalties or threshold values to prevent investors and developers from becoming discouraged (Chapter 15).

Finally, most stakeholders (67.9%) supported importation and sale of GM food products. Of those opposed (30.8%), some justified their opinion due to unknown health effects or by arguing that importation would compromise the country's own R&D and production of GM crops.

24.6.6. Potential effects of demographic factors on attitudes and perceptions of genetically modified (GM) crops

The findings from the present study showed that attitudes and perceptions appeared most deeply embedded in the respondents' general attitude towards GM crops (i.e. perception groups), while occupation, educational level and at times nationality had an impact on the observed differences in stakeholder responses. The effects of factors such as age, sex, income level, upbringing, family background, knowledge of agriculture and rural life, and cultural leaning were evident only for certain issues addressed in the questionnaire. Marital status had no effect.

Perception group (PG) and occupation

Rather unsurprisingly, civil servants from NGOs and respondents from PG1 most commonly express the most negatively inclined attitudes towards GM crops, while the opposite was true for agricultural researchers, civil servants in the public/private sector related to agriculture and at times extension workers, as well as respondents from PG3 and PG4. This is consistent with studies by e.g. Aerni (2005), the United Republic of Tanzania (2012) and Anunda (2014). The two latter surveys found that scientist and experts, as well as agricultural personnel in the study by Anunda (2014), were among the biggest proponents of GM technology. Such findings are likely to reflect the polarised debate on GMOs and imply that opinions could stem from a pre-determined bias, and further challenges the ability to make "true" assessments of e.g. the perceived balance of news reporting (Chapter 10, section 10.5) and public attitude changes (section 25.5.8). Additionally, such findings could also reflect, or be exacerbated by, factors such as hypothetical bias (Box 24.1).

Still, there were a few questions for which there were no significant differences in stakeholder opinions on the basis of perception group and occupation, including the level of influence by anti-GMO groups (Chapter 9, section 9.5), the perceived governmental attitude change (section 24.5.7), and the level of support for strict regulations and labelling of GM products (section 24.5.11). Additionally, occupation had no effect in terms of the perceived importance of regulatory and infrastructural improvements (section 24.5.3), support for sale and importation of GM food crops (section 24.5.12), whether participants had consumed or were willing to consume GM food products (section 24.5.11), the perceived likelihood of commercialisation of GM crops (section 24.5.9), or for most of the concerns associated with GM crops (section 24.5.4). The lack of such significant differences might help support the reality of the situation, and further indicates that stakeholders of various professions and perception groups at times agree on certain aspects of the debate or have doubts about issues such as the potential long-term consequences of the technology.

Education

The effect of education on stakeholder responses was most prominent for concerns associated with GM crops (section 24.5.4), previous consumption of GM food products (section 24.5.11), regulation and labelling (section 24.5.11), sale and importation of GM food products (section 24.5.12), and lifting of the Kenyan ban on GMO imports (Chapter 7, section 7.3.1.3). Generally, those with PhDs made responses in favour of GM crops and expressed low levels of concerns, which might suggest that an increase in educational level may have a positive effect on the acceptance of GM crops. This would be consistent with studies by Hossain *et al*. (2002), Traill *et al*. (2004), Torres *et al*. (2006), Kimenju & De Groote (2008) and Njoka *et al*. (2011).

However, there did not appear to be a consistent, linear relationship between an increase in educational level and positive attitudes and acceptance of biotech crops. For instance, stakeholders with Bachelor and Master degrees were at times found to divide relatively equally across response categories for various questions, though there were several exceptions; for example, the majority of respondents supported strict regulations and labelling of GMO food products (the same was true for those with secondary level education) (section 24.5.11), while there was a high level of support for lifting of the Kenyan ban on GMO imports among those with Bachelor degrees (Chapter 7, section 7.3.1.3). Additionally, participants with Bachelor and Master degrees often expressed relatively high levels of concerns associated with health and environmental effects of GM crops, while the majority of those with secondary level education most commonly expressed low levels of concerns. The latter finding could reflect the proposed effect that education may have on the ability to identify risks (and benefits), for instance in regards to potential long-term effects (section 24.4.4 and 24.4.5) (Berrier, 1987; Stewart, 2000; Bucchi & Neresini, 2002; Koivisto-Hursti & Magnusson, 2003; Moerbeek & Casimir, 2005).

In the case of consumption of food products with GMO content, none of those with PhDs believed that they had not consumed such products, while those with secondary education either were unsure of or had the impression that they had not. This finding appear consistent with a study by Pew Initiative on Food and Biotechnology (2001a) which found that American consumers with higher education were more likely to believe that they had consumed GM food products. A possible scenario is that people with PhD level education have had more travel opportunities and associated more with an international community through their line of work and education, and as a consequence have been, or think they have been, more exposed to GM products.

Nationality

Nationality was a significant variable in explaining differences in stakeholder responses for few aspects addressed in the questionnaire, including the level of awareness of the Kenyan Biosafety Act of 2009 and perception of whether the Act would inspire other African countries to follow suit (Chapter 7); opinions of the Tanzanian and Ethiopian regulatory amendments and of regional harmonisation efforts of laws and regulations governing biosafety and biotechnology (Chapter 7); the perceived likelihood of women becoming negatively affected due to the introduction of transgenic crops (section 24.5.5); and whether to allow for sale and importation of GM food products (section 24.5.12).

It was generally found that the majority of Kenyan and Ethiopian stakeholders made replies in favour of biotech crops and supported various political and regulatory amendments in the East African region, of which the former finding is consistent with e.g. Njoka *et al*. (2011). The majority of Ugandan participants also made responses in favour of GM crops, thought the trend was not always as apparent as for Kenyan and Ethiopian stakeholders. Tanzanian participants generally spread relatively evenly across response categories (for example, an equal number of participants supported the recent amendments made to the Tanzanian Biosafety Regulations, as those that did not support the revision; Chapter 7), though a slight majority at times expressed opinions in less favour of agricultural biotechnology (for instance, the majority did not support importation and sale of GM food products or regional harmonisation of biosafety regulations and policies). This finding appears somewhat consistent with the study by the United Republic of Tanzania (2012), but not necessarily with Mnaranara *et al*. (2017), which demonstrated a high level of positive opinions among certain groups of stakeholders (i.e. regulatory authorities and academics).

One of the hypotheses set by the thesis was that a longer practical history dealing with agricultural biotechnology would facilitate greater knowledge of the topic among stakeholders, which could translate into a higher degree of positive attitudes and perceptions. This appears to hold true in the case of Kenyan, and to a somewhat lesser degree Ugandan, stakeholders. However, the hypothesis fails to explain the high level of positivity among Ethiopian participants compared to Tanzanians, whereby the advent of agricultural biotechnology is comparably recent. However, the political will expressed by the Ethiopian government and scientists do appear to somewhat exceed what has been observed in Tanzania hitherto. Perhaps Ethiopian stakeholders have been less exposed to the biased debate on GMOs and its many controversies, and/or the novelty of the technology has given rise to a higher degree of "technology optimism".

That being said, perceptions of GM crops are influenced by an intricate network of factors that go beyond the mere practical history of dealing with GMO-related issues, including the degree of trust in governments and various institutions, culture and traditions, socio-economic and socio-political conditions, differences in agricultural and environmental constraints (which may impact on the perceived benefits and disadvantages of the technology), the level of impact by NGOs and other external influences, perceived public awareness and attitudes, and various geographical and demographic factors. For instance, respondents from Ethiopia included seven agricultural scientists (all of whom belonged to perception group 3 and 4) and only a single stakeholder from the NGO sector (belonging to perception group 1). In Tanzania, stakeholders represented a wider range of professional backgrounds and perception groups. Thus, especially in the case of Ethiopia, the biased selection of stakeholders challenges the ability to make generalisations.

Finally, in cases where a significant effect of nationality was not found, it implies that opinions are shared across nationalities. For instance, Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders appeared to share a common view of recent governmental and public attitude changes (i.e. towards the positive), as well as perceiving it as highly likely that GM crops would become commercialised in the foreseeable future, which might imply that parts of East Africa is moving in a joint direction in terms of the advent of agricultural biotechnology.

Sex

There were weakly significant differences in the level of concern about "altered social structure" on the basis of sex (section 24.5.4). The majority of male participants were "not concerned" (~62%), while the majority of female respondents divided themselves relatively equally between "not concerned" (~41%) and "somewhat concerned" (~36%). Thus, there did not appear to be a particularly prominent trend whereby respondents of one sex expressed a particularly lower or higher degree of concern. However, a somewhat more distinct effect of sex was evident in terms of paying attention to food labels (section 24.5.11), whereby women appeared more likely to check labels than men (i.e. ~87% of female respondents checked compared to ~55% of male participants). Such findings could reflect that females are still considered the primary decision-makers in terms of grocery shopping and food preparation for their families (Hwang *et al.*, 2005; Moerbeek & Casimir, 2005). However, there were no significant differences in whether participants checked for GMO content on the basis of sex, which indicates that even though women are more aware of labels, they do not consider it necessary to check for GMO content, perhaps as this is not perceived as potentially harmful (though this finding may reflect other factors such as the respondent's perception group or educational level, or whether the country actually has a mandatory labelling law).

Age

There were significant differences in the opinions of whether the Kenyan Biosafety Act of 2009 would inspire other African countries to follow suit on the basis of age (Chapter 7, section 7.3.1.2). All of those aged 40-49 and 60-79, and the majority of those aged 30-39 and 50-59, found this to be true. Half of the participants aged 19-29 did not believe that the Act would inspire other countries to follow suit (note that one third of this age group did not reply). Additionally, age had a significant effect on the opinions of sale and importation of GM food products (section 24.5.12). The majority of those aged 30-49 supported importation and sale; a slight majority of those aged 60-69 did not support importation and sale; while those aged 19-29 and 50-59 spread evenly between the two response categories.

Though there is a lack of any consistent trends, it might appear as those of "intermediary" age groups (i.e. 30-49) are the most positively inclined towards certain aspects of the GMO debate. A possible explanation is that stakeholders of such age groups have had time to develop a broad knowledge base, while still having a sense of "technology optimism" and openness to the technology compared to the more conservative opinions that at times characterise older generations (as seen in studies by e.g. Grimsrud *et al*., 2002; Torres *et al*., 2006; Gaskell *et al*., 2010; Kikulwe *et al*., 2011; Njoka *et al*., 2011; United Republic of Tanzania, 2012). However, as the findings involve intermediary age groups, it makes it somewhat challenging to place it in the context of previously conducted studies. Still, it appears inconsistent with e.g. Hossain *et al*. (2002) (though the most positive included ≤35), Njoka *et al*. (2011), United Republic of Tanzania (2012) and Bugge & Rosenberg (2017), while being consistent with e.g. James & Buton (2003), Payne *et al*. (2003), Alexander & Mellor (2005) and Christoph *et al*. (2008). However, such studies are not directly comparable as they have focused on consumers and farmers, as opposed to stakeholders with a professional involvement in the topic.

Income level

Most studies that have investigated the association between income level and attitudes towards GM food products have focused on consumers. It is believed that food products with GMO content are distributed more commonly to low-income populations (Vecchione *et al*., 2015), and that high-income consumer generally do not have to consider the price of the product when choosing between conventional and GM food items (though it is not always a given that the former is more expensive than the latter) (Nielsen *et al.,* 2003). Xia (2014) found that Chinese consumers with a higher level of income exhibited more negative attitudes and lower willingness-to-buy GM soybean oil, while consumers with lower income were considered more likely to choose this product over the conventional one due to its lower price. Contrastingly, Boccaletti & Moro (2000) found that Italian consumers with higher incomes were more likely to buy GM food products, while Al-Khayri & Hassan (2012) found that Saudi Arabian consumers with middle class incomes were the most accepting of GM commodities; both of which are consistent with the study by Kimenju & De Groote (2008) among urban consumers in Nairobi.

The present study did not find significant differences in stakeholder responses to questions concerning consumption GMO food products on the basis of income level, thus is consistent with studies that have failed to find a significant effect (e.g. Baker & Burnham, 2001). The only question for which a significant effect of income level was found was for the perceived level of influence of anti-GMO groups (Chapter 9, section 9.5). It appeared as if those with moderate (US$400-599) and high (≥US$1000) incomes were more likely to perceive such groups as having a high level of influence compared to those earning less than US$200. However, as discussed in section 9.5, the idea that income level *alone* should impact on the perceived level of influence by anti-GMO groups appear somewhat improbable.

Family background

There were weakly significant differences in terms of whether respondents had consumed GM foods on the basis of family background (i.e. whether participants had been raised in a farm or non-farm family) (section 24.5.11). The majority of respondents from a non-farm family (~73%) had consumed GM food products compared to 37% of those with a farm family background. Furthermore, those with a farm family background appeared to display a higher degree of uncertainty; ~52% of those with a farm family background did not know whether they had eaten GM food products compared to 20% of those with a non-farm family background. This finding may indicate that those being raised in non-farm families have had, or believe they have had, greater exposure to commodities with GMO content.

Family background also had a significant effect on the perceived importance of improving regulatory and infrastructural short-comings before the advent of GM crops (section 24.5.3). Those with a non-farm family background divided themselves relatively equally across response categories (though the fewest number of respondents were found to “strongly disagree”), whereas those from a farm family appeared more likely to either “strongly disagree” (~42%) or “strongly agree” (~34%). Thus, those with a farm family background appear more strongly opinionated on the matter, and more likely to “strongly disagree” than those with a non-farm family background.

Upbringing

There were significant differences in the level of concern associated with potential negative health effects of GM crops on the basis upbringing (i.e. whether participants had been raised in a rural village, small town or big city) (section 24.5.4). It appeared as if those that had grown up in a city were less likely to be “very concerned” (~7%) compared to those growing up in a small town (~38%) and rural village (40%). Thus, one could hypothesise that stakeholders that have grown up in an urban city environment are less worried about potential health risks than those being raised in rural areas or smaller towns, which could perhaps be seen in conjunction with other demographics such as higher educational levels. That being said, the majority of those growing up in a small town (~38%), and several of the respondents from rural villages (25%), were “not concerned”, which challenges this assumption.

Knowledge of agriculture and farming life

There were significant differences in the opinions of GM cash crops on the basis of the stakeholders’ level of knowledge of agriculture and farming life (i.e. “not much”, “know enough” and “very knowledgeable”) (section 24.5.2). All of those that characterised themselves as “not very knowledgeable” considered the commercialisation of such crops “favourable” (note that half of this demographic group did not respond to the question). Contrary, the majority of those that considered themselves “adequately knowledgeable” (~53%) and “very knowledgeable” (~54%) found the commercialisation of GM cash crops “strongly favourable”. This observation could imply that stakeholders that exhibit a higher level of knowledge of agriculture and farming life are more positive towards the advent of GM crops. Still, a similar effect was not found in the case of transgenic food crops (though this could reflect the fact that the acceptance for such crops is generally lower than for cash crops) or for any other questions that measured the level of acceptance of biotech crops (e.g. “how much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country”), thus there was a lack of any consistent trends.

Cultural leaning

Interestingly, though the effect of cultural leaning was only weakly significant, all of those that characterised themselves as liberal culturally perceived the Kenyan Biosafety Act of 2009 as “wise and timely” (Chapter 7, section 7.3.1.2). This might indicate that culturally liberal respondents are more open towards the advent of biotech crops and laws & regulations that facilitate R&D and commercialisation. However, the large majority (~69%) of those that characterised themselves as moderate culturally also found the Act “wise and timely”. Furthermore, this was the only question for which a significant effect of cultural leaning was found, thus there appeared to be a lack of consistency.

24.7. Chapter 24: Concluding remarks

The present study set out to investigate the level of awareness, attitudes and perceptions of biotech crops among a range of stakeholders from Kenya, Uganda, Tanzania and Ethiopia, including rural farmers from the former three; how such factors have changed with time and how they may differ within and across countries; and the variables that might help explain the observed differences and similarities, including demographic factors, the general attitude towards agricultural biotechnology, the effect of acquisition of novel information, source of information, and risk perception.

Awareness, perceptions and acceptance of genetically modified (GM) crops among East African farmers and other stakeholders

With the exception of the study by Mnaranara *et al*. (2017) among Tanzanian farmers, the present study was correct in assuming that the level of awareness of GM crops had increased among farmers since previously conducted perception surveys, though it was not possible to ascertain for the Ugandan farmers (due to lack of prior studies).

In most cases, there were significant differences in the level of awareness, favourable impressions, perceptions and acceptance of biotech crops among farmers across study countries, while differences based on nationality were less evident among stakeholders with a professional involvement in the topic. The study hypothesised that Ugandan and in particularly Kenyan farmers and stakeholders would exhibit the highest level of awareness and favourable attitudes and perceptions due to the countries' longer history of dealing with the technology. Consistent with this idea, Kenyan farmers were found to exhibit the highest level of awareness, and the majority of both farmers and Kenyan stakeholders expressed favourable impressions and perceptions of biotech crops. The majority of Ugandan stakeholders usually expressed positive attitudes towards GM crops, though the trend was not as distinct as for Kenyan participants.

However, contrary to the hypothesis, Ugandan farmers exhibited the lowest level of awareness and favourable impressions of GM crops, while Tanzanian farmers were somewhat more aware and the most positive towards the technology. Tanzanian stakeholders did not share the same degree of favourable perceptions as Tanzanian farmers, and at times times expressed the most negatively inclined opinions out of the four nationalities. Ethiopian stakeholders on the other hand, were found to express very high levels of favourable perceptions of biotech crops

Still, regardless of the level of awareness and initially recorded impression of GM crops, the majority of farmers across all study countries would grow GM crops if given the opportunity, believed that the technology could help improve the quality of life of farmers, and supported the commercialisation of biotech crops. Additionally, overall, the majority of other stakeholders expressed positive attitudes and perceptions towards the advent of GM crops, as well as perceiving the recent governmental and public attitude changes as having been in favour of the technology. That being said, farmers and stakeholders expressed concerns about potential health, environmental, trade and socio-economic effects, and further stressed the importance of safeguarding traditional varities, employing conventional measures, and further develop the regulatory and infrastructural capacity.

The effect of demographics and other factors on awareness and perceptions among East African farmers and other stakeholders

Among farmers, education, sex, marital status and cultural leaning had significant effects on awareness, attitudes and acceptance of GM crops in one or several of the study countries. For instance, an increase in the level of education appeared to have a positive impact on awareness and/or impressions of biotech crops among farmers in all study countries, while Kenyan farmers that characterised themselves as conservative culturally had tendency to display negative attitudes and perceptions of the technology. However, some of the effects were often "sporadic" and lacked consistency (e.g. a linear relationship between the variables being investigated). Thus, other factors are likely to be at play, including basic knowledge of the technology, previous exposure to the GMO debate and its many controversies (which may reflect the type of information channel), differences in risk/benefit perception, the level of trust bestowed on governments and various institutions, and various other cultural, socio-economic and socio-political factors.

In the case of the stakeholders, opinions appeared most deeply embedded in the respondents' general attitude towards the technology (i.e. perception group) and occupational group; two factors which are likely to be closely related. Additionally, education and nationality occasionally had significant effects, especially in regard to the level of concern about potential negative impacts of GM crops and various issues related to laws and regulations governing the technology, respectively. However, it is likely that the effect of nationality at times reflected other factors such as perception group and occupation. Finally, demographic such as age, sex, income level, family background, upbringing, knowledge of agriculture and farming life, and cultural leaning were found to have an effect, though these were often only weakly significant and further displayed a lack of consistency. Still, there were some intriguing findings, such as the association between sex and paying attention to food labels.

Limitations, indications, applications and directions for current and future perception studies

What has become apparent through both the present study and previously conducted perception surveys is that the effect (or lack thereof) of demographic factors on awareness, attitudes and perceptions may vary substantially within and between countries, perhaps even more so between developing and developed countries (thus, results obtained from some of the studies presented in previous sections are not necessarily applicable to the East African situation). Variable results highlight the complexity of the underlying behavioural mechanisms, and are likely to reflect geographical differences in socio-economics, culture and tradition, cognitive factors and behavioural response attitudes, trust and risk perception, market structure, economic development and industrialisation, the public debate and governmental action, and so forth (e.g. de Cheveigné *et al*., 2002; Springer *et al*., 2002; Grimsrud *et al*., 2003). As such factors change, attitudes and opinions are likely to adapt as well, and at times rapidly.

Furthermore, making generalisations and comparisons on the basis of perception studies is challenged by differences in the method of sampling, date of conduction, survey sites, context of analysis, and the lay-out and formulation of the questionnaire (Bonny, 2003), as well being limited by the geographical range and small sample sizes commonly observed for perception studies related to agricultural biotechnology (Boccaletti & Moro, 2000). For instance, as observed in the present study, differences in sample sizes and the response rates for various questions is likely to have be an influential factor on the observed differences in awareness and attitudes between countries.

Still, perception studies provide important information for policy and regulatory decision-makers, biotech companies, agricultural researchers and civil rights organisations that can be employed when designing and developing agricultural policies, agri-biotech crop programs, awareness campaigns, and risk-communication and marketing strategies. For instance, perception studies can help identify the most pressing concerns among farmers, consumers and other stakeholders, which may work to constrain the adoption of biotech crops if not taken into consideration. Additionally, perception surveys can be useful in identifying particular geographical regions or demographic groups (e.g. the rural poor, women and the elderly) for which outreach and awareness efforts should first and foremost be aimed at, which may further help counteract potentially negative socio-economic impacts.

Additionally, as observed in the present study, opinions and perceptions are often deeply embedded in the respondents' general attitude towards biotechnology, which reflects the polarisation of the GMO debate. In this respect, it is important to improve communication among stakeholders; establish clear, trustworthy, credible and tangible sources of information that is accessible to all (including the general public, journalists, the civil society, and policy and lawmakers); and create policies for enhanced acceptance of agricultural biotechnology which operate within several sectors (e.g. the media houses and the educational system). Furthermore, it is essential to establish trust and credibility in and between institutions, regulatory agencies and governmental bodies involved in the environment, health, agriculture and food, for which some of the surveyed stakeholders and farmers expressed some level of mistrust towards (Fransen *et al*., 2005).

Finally, perception studies indicate that acceptance in the form of willingness-to-buy, willingness-to-grow and support of commercialisation appears to be the highest when there is a perceived direct benefit to the consumer and farmer, respectively. Such findings are promising for the introduction of second-generation GM crops which provide benefits to both producers and consumers – for which many East African farmers represent both. It further underlines the importance of identifying which characteristics consumers and farmers look for when deciding whether or not to accept a certain product (e.g. taste, quality, durability, marketability and early maturity as identified by the surveyed farmers). This will also provide farmers, gatekeepers and businesses with a sense of security that their products will find their way to a market where consumers are willing to pay the same price as for non-GM products; a highly prominent concern expressed by farmers from all study countries.

Future studies should attempt to further disentangle the underlying behavioural mechanisms of perceptions and acceptance of biotech crops among consumer, farmer and other stakeholders in East Africa; investigate the link between consumers' preference and willingness-to-buy to farmers' tendency to adopt GM crops (Smale *et al*., 2009); and explore which measures are most efficient at raising awareness and enhancing education. For the latter, methods such as focus groups and interviews may provide valuable insight, as opposed to studies that rely mainly on quantitative and deterministic methods; it is important to find ways to talk with, not simply to, farmers (Schnurr & Mujabi-Mujuz, 2014). Indeed, if there is one thing that the farmer surveys have shown, it is the ability, eagerness and willingness of farmers to learn more about the underlying technology, and the desire for more information, demonstration plots and field trials to help facilitate a more thorough understanding.

Chapter 25. Design and Execution of the Social Science Study: Challenges and Improvements

This chapter will consider some of the obstacles and short-coming that became apparent both during and in the aftermath of the farmer and stakeholder surveys, and how such factors could have been avoided or potentially improved on in future studies.

25.1. Farmers surveys

25.1.1. Comments: Kenyan farmer study

Based on the personal participation on the first and last day of the field survey in Kenya, as well as comments made by the data collection team, several remarks and points of improvement were made:

1) Originally, the idea was to collect data on an individual farmer-level (i.e. whereby a single questionnaire was filled out for each respective farmer through an interview-like approach). However, it quickly became apparent that this was not feasible due to time, budgetary and socio-economic constraints. For instance, ICOSEED did not have the capacity to print out the required number of questionnaires and did not have adequate human resources for one-on-one interveiws. Such issues are also explained by a lack of appropriate communication; if such obstacles had been identified prior to commencing, one could have tried to find ways to work around such problems. For instance, perhaps IITA could have helped provide human resources and/or printed copies of the questionnaire, or one could have filled out questionnaires using lap-tops. Consequently, it was determined to collect the data on a group-level and a show of hands was implemented in hopes of capturing some of the variability within the group.

2) Some farmers were naturally more vocal than others, while some did not speak at all. Though silence might indicate consent, the team was asked to ensure to engage all participants.

3) Most farmers appeared to demonstrate a high degree of trust in ICOSEED. Thus, it was pivotal that the team remained as objective and impartial as possible to avoid any biased responses. The translator stressed the importance of the farmers speaking freely, independently and without fear. It appeared as if the farmers valued such statements and acted accordingly. Such an approach could also have minimised hypothetical bias despite not performing “cheap talk” as suggested by Lusk (2003) (Box 24.1).

4) Participation often varied substantially from the target number of 10-15 farmers per group. If participation was lower than 10, a re-run was conducted. In cases where the attendancy was particularly high (i.e. 25-40 farmers), the survey was carried out as normal, but with the potential consequence of imposing delays and making it more challenging to keep track of answers and opinions.

5) The conduction of the survey was at times delayed as farmers did not show up on time. This is likely to reflect miscommunication between ICOSEED and the farmers, limited travel opportunities of farmers (though the meeting places were usually in the vicinity of the farmers’ homes), infrastructural short-comings, and other responsibilities that required more

immediate attention by farmers. In this respect, it could have proved advantageous to conduct household surveys.

6) Due to heavy rains and poor infrastructure, some areas and villages were very hard to reach, which caused delays in the conduction of the survey in certain areas (also related to point (5) above).
7) Some farmers were not comfortable providing certain demographic information such as age and educational level. As a consequence, this type of data was not always provided.
8) For the question concerning religious/cultural concerns associated with GM crops, cultural misgivings were considered the most important by farmers. This notion was also made during the Ugandan and Tanzanian surveys. Thus, in order to get a true impression of the level of concern for religious and cultural factors separately, it could have been useful to divide the question into two. Additionally, an option for ethical concerns, either by itself of grouped together with religious concerns, could also have been included (this also applies to the Stakeholder questionnaire).

Based on some of the observations above, a set of practical guidelines was made and employed during the surveys in Uganda and Tanzania to ensure consistency. Additionally, the data collection for the latter two surveys consisted of people with knowledge of the local language, the agricultural system, and the socio-economic and socio-cultural norms in the respective country. Consequently, it was assumed that all surveys were carried out in a satisfactory manner (i.e. using a participatory and objective approach), despite personal absence during the data collection.

25.1.2. Comments by data collection team: Ugandan field survey

As observed during the Kenyan survey, some of the Ugandan farmers felt uncomfortable providing certain demographic information. No further comments were made by the data collection team.

25.1.3. Comments by data collection team: Tanzanian field survey

As for the Kenyan survey, the team noted that the number of participants varied from the target number of 10 (note that no re-runs were conducted), and some of the villages were hard to find or difficult to reach due to infrastructural limitations. In certain groups, some farmers were reluctant to respond, saying that they had answered questions from researchers in the past without hearing or seeing from them in the aftermath of the surveys. As a consequence, the farmers had developed what appeared to be some degree of mistrust towards researchers and studies of this kind. In this respect, the data collection team, the extension workers and the village leaders did their best to convey the significance of the survey.

25.1.4. Hand-over and quality of the data

The data from the Tanzanian survey was handed over as an excel spread sheet and in satisfactory condition (with the minor exception being that the number of respondents at times exceeded the total number of farmers). The completed questionnaires from the Kenyan and Ugandan surveys were handed over simultaneously and as original hard copies. Some of the data was not of satisfactory standard, including (i) being difficult to interpret (e.g. due to poor handwriting); (ii) missing pages; (iii) inconsistent number of farmers answering the questions throughout a specific questionnaire; (iv) in some of the cases whereby a re-run had been conducted, the answers given the first time around could be completely different from the second run (for instance, favourable impressions of GM crops had been recorded during the first run, while farmers were found to exhibit unfavourable impressions during the second one); (v) no distinction had made between the Ugandan farmer groups according to district (i.e. Wakiso, Mukono, Mpigi and Luwero), thus making it investigate the relationship between awareness and attitudes and geographical locations.

Some of the above-mentioned mistakes are as expected for surveys of this nature. Though many of these inconsistencies were later clarified, it proved very challenging to get hold of ICOSEED in the aftermath of the study. Part of the reason was due to lack of power and internet connection, as well as severe drought and outbreak of cholera which the organisation had to devote their time to (as explained by ICOSEED). Still, the experience demonstrates the importance of being more personally involved in every step of the conduction of the survey (including the pre-tests) to ensure that the data obtained is of the required standard. Unfortunately, consistent personal participation was not considered possible due to safety, time and budgetary constraints. In this respect, a more thorough and specifically aimed training of the enumerators and improved communication could have proved advantageous.

Finally, some of the above-mentioned challenges highlight issues that might arise when conducting studies in countries with different socio-economic, socio-political, cultural, infrastructural, and climatic and geographical factors from what one is normally used to, which should be considered closely before embarking on similar studies.

25.1.5. The study design and its implications for data analysis

25.1.5.1. Lack of randomly selected and representative sampling

In retrospect, it became apparent that the data were non-randomly selected and non-representative. For instance, the selected study sites and farmers groups in Kenya were based on areas in which ICOSEED had performed previous activities and had contact farmers available. A similar approach was used during the Ugandan survey, where contacts of ICOSEED helped put the organisation in touch with extension workers and farmers groups. Additionally, the relatively small sample size obtained in Uganda limited its representativeness. Also, as already touched upon (Chapter 24, section 24.4.1), the choice of survey sites in Tanzania was based on the idea that some level of awareness would exist here.

Non-random sampling introduces sampling errors and bias (e.g. in terms of the level of awareness and/or attitudes towards GM crops), and could result in over- and/or underrepresentation of certain demographic groups (Box 25.1). Furthermore, non-randomly selected data is strictly not subject to standard statistical tests and will cause results to be systematically erroneous, thus creates implications when performing statistical analyses. All of these factors decrease the degree of confidence when making statistical inferences and generalisations, and one has to be very cautious when making assumptions or drawing conclusions based such findings.

That being said, given constraints dictated by human and monetary resources, the time frame, safety aspects and accessibility to farmer groups, the only alternative approach would have been to investigate perceptions among farmers from a small area outside Nairobi (i.e. whereby IITA was carrying out research activities). This would have resulted in a much smaller and less representative sample than what was achieved using the aid of ICOSEED.

Box 25.1. How do the demographics of the surveyed groups fit into the "demographic landscape" of the study countries?

Though it does not make up for the lack of non-randomly and non-representative selected data, it may be of interest to evaluate whether the surveyed farmers exhibited socio-demographic characteristics similar to what has been recorded on a national or regional level.

There were at least two demographic factors for which the number of respondents could be considered lower than anticipated. Firstly, considering that Islam is the second biggest religion in East Africa, one might have expected a higher degree of Muslim farmers in the Kenyan and Ugandan surveys (though this will depend on geographical factors, for which the author has limited knowledge). Additionally, though females do not dominate the agricultural sector in Tanzania to the same degree as in Kenya and Uganda (i.e. ~54% compared to 70-80% in Uganda and Kenya) (FAO, IFAD & ILO, 2010; World Bank, 2011b; Uganda Bureau of Statistics, 2012), one would have expected the majority of Tanzanian farmers to have been female. The lack of female participants may reflect that men are often the primary decision-makers and/or that women are more bound by household tasks which could limit travel opportunities and participation in studies like this.

Additionally, as touched upon in Chapter 2, the average age of the East African farmer is increasing. Unfortunately, it was not possible to determine the average age as the information was usually given as a range (i.e. from the youngest to oldest) or as a cut-off point (i.e. respondents were above or below a certain age). Furthermore, age was one of the factors which some farmers were reluctant about sharing. Still, it appeared as if a range of age groups, including younger farmers, were present during the surveys.

For all other demographics, the data appeared relatively consistent with what is reported in the literature. In terms of marital status, one would expect a high degree of farmers to be married, or potentially widowed, based on what is known about the average age of marriage (United Nations, 2015). A study by Ngeywo *et al*. (2015) also found that the majority of surveyed Kenyan farmers in Kisii County were married (though not to the same degree as observed during the Kenyan survey). The average recorded land holding fell within the range calculated by FAO (though some of this information is up to 12 years old) (FAO, s.a.-a). In terms of the level of education, the findings are consistent with statistics provided by UNICEF and FAO, whereby the Kenyan public/farmers generally have the highest achieved level of education, followed by Ugandans and Tanzanians (UNICEF, 2016; FAO, s.a.-a).

Finally, little or no information is available on how the East African farmers categorise themselves culturally (i.e. cultural leaning).

25.1.5.2. Implications of having to deal with group-level data

A result of the study design was that only group-level data was available. Certain types of information are lost when moving from the individual to the group-level. For instance, it is not possible to link responses to specific farmers, which makes it impossible to ascertain whether a particular response group consist of the expected respondents, such as whether only GMO aware farmers replied to questions where this was intended as a prequisite (e.g. "what is your impression of GM crops?"). Other complicating factors include variation in group size or lack of variation in demographic characteristics between groups, as the former will reduce the comparability between groups and the ability to make generalisations across groups, while the latter makes it challenging to decipher the potential effects of demographics on attitudes and perceptions.

Furthermore, a consequence of working with group-level data is that one has to deal with the bound nature of proportions, i.e. that all the observations fall between 0 and 1. For instance, as the mean proportion start approaching 0 or 1, the variance will start approaching 0. This cause errors to become heteroscedastic (i.e. the variance of errors/residuals are not constant across the predictor variable, i.e. x values), thus violating the assumption of homoscedasticity of errors of linear regression models (i.e. the variance is equal across the range of x) (Long, 1997). Additionally, linear regression models are very sensitive to outliers (Williams, 2016), which was a relatively common occurrence in the data sets. Such factors made it challenging to employ standard estimation models such as linear regression and general linearised model (both using IBM SPSS Statistics 21 and "R"). Thus, a specifically designed simulation model was employed (see below).

25.1.5.3. Monte Carlo simulation model for contingency table analyses I: Opportunities and challenges

The simulation model used to investigate correlations was developed by Professor Arne Huseby at the Department of Mathematics at the University of Oslo (Huseby *et al*., unpublished data). By considering the farmer groups as the "individuals", the model avoids problems related to variation in group size, which normally would reduce the degree of comparability between farmer groups. The model further estimates the correlation coefficient between the characteristics of each group. The p-value is calculated based on a Monte Carlo simulation, which differs from a standard chi squared test where the p-value is estimated based on a chi squared distribution. The Corr(X1, X2) value, which was randomly labelled "c", represents the strength and direction of the correlation, while the sample size constitutes the number of farmer groups being compared, which equals to the number of rows of the given contingency table. Additionally, the model produces values for Chi(X1) and Chi(X2), as well as an LCorr(X1, X2) value ("logc"), which are described below.

Logit transformed data (logc)

Logit transformation (Appendices 1, Appendix F) is a relatively common procedure when having to deal with fractions, as it allows one to circumvent issues that arise when the fraction is getting close to 0 or 1 (as described above). It does so by extending the fractional domain from 0 to 1 to $-\infty$ to $+\infty$, which cause correlations/covariances between proportions that are close to 0% and 100% to be "weighed more heavily" than for normal correlations (whereby all correlations weigh the same). In other words, when a significant result is only evident for logit correlations, it indicates that the correlation is strongest when dealing with proportions near 0% and 100%.

Group equality (Chi(X1) and Chi(X2))

A problem encountered when estimating the correlation coefficient was that the groups were found to be significantly different for more or less all of the relationships tested (i.e. the p-values calculated for Chi(X1) and Chi(X2) seen in tables of Appendices 1, Appendix D.9).

The empirical correlation coefficient can be calculated regardless of whether there is any significant difference between the groups or not. However, problems arise when estimating the distribution of the correlation coefficient (Z) (Appendices 1, Appendix F) under to the null hypothesis (i.e. that the X and Y variables are independent). When this assumption is violated, one cannot rely on the estimated distribution of the correlation coefficient and consequently neither the estimated p-value.

As an example, imagine that X denotes the number of female farmers and Y denotes the number of farmers with a favourable impression of GM crops. The aim is to calculate the correlation between X and Y, i.e. Corr(X, Y) or "c", using the empirical correlation coefficient Z for X and Y based on the data from a specific number of groups. Thus, let M_n denote the number of respondents in nth group, Xn denotes number of females in nth group and Y_n denotes the number of farmers with favourable impressions of GM crops in nth group, whereby n denotes the number of groups. Consequently, $X_n=S_n / M_n$ and $Y_n = T_n / M_n$.

Thus:

$M = M_1 + M_2 + … + M_n$ = total number of respondents.
$S = S_1 + S_2 + … + S_n$ = total number of female farmers.
$T = T_1 + T_2 + … + T_n$ = total number of farmers with a favourable impression of GM crops.

In order to determine the distribution of Z by simulation, it is assumed that:

1) $S_1, S_2, …, S_n$ are independently binominally distributed with the parameters of $M_1, M_2, …., M_n$, respectively, and with a common probability of success p.
2) $T_1, T_2, …, T_n$ are independently binominally distributed with the parameters of $M_1, M_2, …., M_n$, respectively, and with a common probability of success q.

The size of p and q are unknown, but can be estimated to be p*=S/M and q*=T/M under the assumption of (1) and (2) above. Thus, p* is the total fraction of female farmers in the population, while q* is the total fraction of farmers with a favourable impression of GM crops. Additionally, the Si and Ti-values are independent under the null hypothesis. As a result, there is now enough information to simulate and estimate the distribution of Z.

The heart of the matter is the assumptions that the Si-values and Ti-values have a common probability of success p and q, respectively. When the simulation model tests for "Group equality", it tests the hypothesis that there is a common probability of success (either p or q), which is done using a standard chi squared test. This is tested separately, thus two sets of results are generated (i.e. the Chi(X1) and Chi(X2) values in the tables in Appendices 1, Appendix D.9).

If these assumptions are violated, one has to calculate the probability of success for each group separately, which makes the model break down as there are too many unknown parameters to estimate. In practical terms, it would be impossible to get any significant conclusions by doing this, and there is currently no method of dealing with significantly different groups for this particular model. That being said, this does not mean that calculating the coefficient is without value, but one has to be cautious when drawing any conclusions based on such results. Additionally, lack of group equality is not a substantial problem when relationships are found to be non-significant, which is also considered important findings. Furthermore, the fact that the groups were found to be significantly different can be considered a finding in itself, and indicates heterogeneity among groups, perhaps as a result of geographical and demographic factors.

Covariance and logit covariance

The model also allowed for an estimation of the covariance and logit covariance (Appendices 1, Appendix F). However, such investigations did not provide additional information or substantially different results compared to estimations of the correlation value. Furthermore, covariance is generally more challenging to assess as it depends on the scale of measurement (thus, if two variables exhibit a high degree of variance, the covariance will commonly also be high even though the dependence between the variables is not) (Huseby, pers. comm.). Based on such considerations, the covariance and logit covariance values were excluded from the tables in Appendices 1, Appendix D.9).

Implications of having more than two response categories

Correlations can only be estimated for two variables at a time, which may pose a challenge when there are more than two response categories (e.g. "no opinion" or "do not know"), or when certain questions are left unanswered by several of the participants. In the present study, such analyses were still performed without problems. However, based on these considerations, certain analyses, such as the relationship between the sources of information and farmer impressions of biotech crops, were bypassed.

25.1.5.4. Potential improvements of the study design and questionnaire

Some of the short-comings of the study design are most likely explained by the lack of prior knowledge within the social sciences and experience in carrying out perception studies. This should have been considered more closely before commencing the study, as well having made sure to acquire the appropriate prior knowledge on how to execute such surveys (see e.g. "Alternative approaches to study design" below). Additionally, the approach to data analysis should have been considered prior to the study, including the choice of analytical tool (e.g. SPSS, R or STATA), the appropriate unit level of analysis (e.g. individual, household, or community-level), which x and y relationships one wished to investigate, and the type of analysis (e.g. linear or multinominal regression, generalised linear model, etc.).

Choosing the appropriate unit level of analysis

The obstacles encountered as a result of having to deal with group-level data could have been circumvented by collecting individually-labelled data. That being said, there is currently little available and quantified information on how different stakeholders and farmers in East Africa perceive GM crops, which makes it challenging to choose the appropriate unit of analysis. Furthermore, given the nature of the issue (e.g. in terms of the current level of awareness and policy environment sorrounding GMOs), it might be just as useful to investigate and understand how GM crops are adopted on a community-level. Subsequently, in a possible scenario in which biotech crops are approved and adoption become a matter of individual decision-making, household-level or individual farmer-level data would make more sense. For this purpose, a good qualitative analysis represents a good contribution to what is lacking in quantified information, and could help lay the foundation for future research in the event of GMO approval in East Africa.

Alternative approaches to study design

Previously conducted perception studies provide valuable insight into how the study could have been executed in order to achieve randomly-selected and representative data. Njoka *et al*. (2011) employed a range of sampling techniques, including simple random (i.e. randomly selecting a sample from a larger set) and systematic sampling (i.e. choosing a fixed starting point, such as a list of all potential participants, and subsequently employ a constant interval, for instance number of people, to allow for selection of participants), as well as non-probability sampling (i.e. non-representative), such as convenience (i.e. employing the best available sample, which could be considered similar to the approach of the present study) and purposive/snowball sampling (i.e. a subset of the population is selected for investigating a specific purpose) (UCDavis, s.a.-b). Kagai (2011) used a pre-prepared list of survey sites which contained the appropriate type of respondents, and subsequently randomly selected areas and respondents. Kimenju *et al*. (2011) used household-level data, whereby 16 sub-locations were randomly selected for each agro-ecological zone, after which households and respondents were selected using simple random sampling. In Uganda, Kikulwe *et al.* (2011) used a multi-stage sampling approach, in which 421 respondents were randomly selected from a community listing (from 21 randomly selected communities). In Tanzania, the survey carried out by the United Republic of Tanzania (2012) employed randomly selected agro-ecological zones, though the further choice of survey sites were dictated by time and budgetary constraints, as well as accessibility.

Pilot study

A pilot study can be extremely valuable before launching a full-scale project, as it can allow one to determine, amongst other: (i) the sampling size necessary to obtain a representative selection; (ii) the acceptable sampling error rate; (iii) the type of data obtained (e.g. whether categorical or continuous); and (iv) how best to proceed with the data analysis. In some respects, the test runs performed for the present study could be considered a type of pilot study, though this only provided information on how well the questionnaires worked in the field, the optimal group size, etc.

Lay-out of the questionnaire

The lay-out of the questionnaire could have been improved in order to help avoid discrepancies between the expected and observed number of respondents, which caused distortion of the data and challenges during data analysis. For instance, the question “are you aware of genetically modified crops” could be interpreted as either whether participants had simply heard of the word “genetically modified crops” or whether they had more in-depth knowledge of the subject (the former was the intended interpretation during the development of the questionnaire). Consequently, it could have been advantageous to have formulated the question differently, e.g. “have you heard of the word genetically modified crops?”, as well as included a question which helped determine the level of knowledge and/or to ascertain the respondent’s understanding. Furthermore, it should have been clearly communicated to both the data collection team and the farmers when certain questions pre-supposed awareness of GMOs.

25.2. Stakeholder survey

In the aftermath of the project, several short-comings and points of improvement for the stakeholder survey became apparent, some of which are listed in subsequent sections.

25.2.1. Inadequate number of respondents

The goal of acquiring 25 respondents from each stakeholder group was not achieved, thus the study failed to provide a representative selection of respondents. Acquiring the contact information of the appropriate stakeholders, getting respondents, and following up on those that agreed to participate proved very challenging. The email was phrased in a way which conveyed the importance of the study and its findings, though it might have come across as somewhat generic. Thus, a more effective approach was to distribute the questionnaire via people at top positions at certain organisations and institutions. Unfortunately, such chief contact persons were not always available.

Additionally, some of the stakeholders said that they had participated in similar surveys in the past, where their opinions had not been fully reflected or the researchers failed to share the findings in the aftermath. Thus, mistrust appeared to be an issue, which might help explain why some NGOs and other stakeholders did not respond or partake even after having agreed to do so. A way of establishing trust could have included sharing of the final report (this was offered to those who requested it) or arranging some form of workshop for all the participants to discuss the main findings. However, the latter approach was deemed impractical due to constraints dictated by limited travel opportunities, time frame, budget and lack of other resources.

25.2.2. Biased representation of certain stakeholders and demographic groups

Most respondents were of Kenyan nationality, thus the findings are most representative of the Kenyan situation. Furthermore, male respondents, certain professional groups (i.e. agricultural researchers, civil servants employed in the public/private sector related to agriculture, and civil servants from the NGO sector), Christians, and participants of perception group 3 and 4 were overrepresented. The biased representation of certain occupational (e.g. researchers) and perception groups could have given the impression that GM crops have a higher level of support among East African stakeholders than is actually the case.

The above-mentioned sampling bias may be explained by a number of reasons: (i) due to the long history of practical experience and regulatory decision-making associated with biotechnology, Kenya has a higher number and a wider range of stakeholders involved in the topic when compared to e.g. Ethiopia and Tanzania; (ii) being situated at a research station in Kenya, it was easier to get in contact with agricultural scientists, as well as Kenyans; (iii) most people at higher positions (e.g. governmental representatives) have highly tight time schedules and might find it difficult to spare the time to participate in studies one of this nature. Furthermore, governmental representatives, policymakers and legislators may be more cautious about participating in a study that touch upon a relatively controversial topic; and (vi) cultural, socio-economic, political, infrastructural and/or bureaucratical factors (for instance, some stakeholders raised issues concerning the socio-economic situation in their country, war and conflict, and/or lack of adequate internet connection). Such factors can also help explain why the study failed to acquire the target number of participants.

In this respect, it could have been more practical to focus on one study country and/or fewer groups of stakeholders. However, as the thesis set out to investigate the full range of dynamics and attitudes, and the changing climate concerning GMOs currently taking place in East Africa, it was deemed necessary to include all stakeholders of all nationalities. Still, if one assumes that opinions are relatively predictable based on certain demographic (e.g. occupation) and perception groups, then the data at hand might provide some indications of the general attitudes of certain groups of stakeholders, and perhaps even some clues as to what the future might hold for GM crops in the East African region.

25.2.3. Lack of certain important stakeholders: Students and the general public

The study could have included young farmers and students involved in agricultural research, conservation, law, biology, social sciences and so forth, who not only represent the generation that could perhaps be the biggest beneficiaries of the technology, but also the future decision and policymakers. Additionally, though farmers and professional stakeholders can be considered as part of the public, an important consideration is the attitude of the “man in the street” and the common dwellers and consumers, which is pivotal for the successful widespread acceptance of the technology.

25.2.4. Monte Carlo simulation model for contingency table analyses II: Opportunities and challenges

A small and biased sample size has implication for the statistical analysis. For instance, one of the occupational groups contained as few as two participants, while another contained as many as 21. The common chi squared test is very sensitive to sample size and cells with zero and near-zero expectations (Huseby, pers. comm.). Thus, a common solution is to merge groups that share certain similarities. However, this was not always appropriate (e.g. in terms of occupational groups), and in the case where an attempt to collapse groups was carried out (e.g. for income level, educational level and age), they were still of insufficient size.

Consequently, in order to circumvent such issues, a specifically designed Monte Carlo simulation model was developed by Professor Arne Huseby at the Department of Mathematics at the University of Oslo (Huseby *et al*., unpublished data). Note that the same model was employed for investigating the effect of geographical location on farmer responses, though the issue of having to deal with small sample and group sizes was not a problem during such investigations (though the model did account for differences in sample size among nationalities).

The simulation model is based on the standard test statistics of the chi squared distribution test, which investigates whether two variables are independent. Thus, a chi squared value (Chi sq.) was estimated, along with the degrees of freedom (Degr. fr, df) and the sample size (i.e. the number of stakeholders/farmers) (Appendices 1, Appendix F). However, similarly to the simulation model for investigating correlations (section 25.1.5.3), the p-value was estimated based on a Monte Carlo simulation as opposed to a chi squared distribution. Additionally, the value labelled Q (as observed in the tables of Appendices 1, Appendix D.6-D.8 [farmer data] and E.4 [stakeholder data]) represents the statistical significance one would get by employing the standard chi-squared test, and is included as a comparative measure to demonstrate how well the two models match.

As already touched upon, the model only provides information about whether or not a significance exists, but does not indicate between which variables or the most important effects. Thus, this had to be assessed by eye using descriptive statistics (e.g. cross-tables, diagrams and percentage levels), which proved somewhat challenging when the significance was low and/or when tables were larger than 2x2. Furthermore, one has to be cautious when drawing any conclusions based on such assessment, and more thorough statistical tests are needed to determine if such evaluations holds true or not.

Finally, during such evaluations, it became apparent that it would have been useful to collapse certain demographic groups (e.g. those aged 60-69 and 70-79, those exhibiting lower level education, and civil servants (1) and civil servants (2)) – despite employing the Monte Carlo simulation model – as certain underrepresented groups had a tendency to be overlooked or dismissed during the descriptive assessments. Additionally, by collapsing or limiting the number of response categories (e.g. “not concerned” and “somewhat concerned”, and “concerned” and “very concerned”; “strongly unfavourable” and “somewhat unfavourable”, and “favourable” and “strongly favourable”; etc.), it would have made it easier to assess the potential demographical and geographical effects.

25.2.5. Improving the lay-out of the questionnaire

One respondent from a farmers’ network organisation felt that the questionnaire was more suited for governmental officials, law and policymakers and educated urban dwellers. Another respondent found some of the questions subjective and felt uncomfortable giving YES/NO answers, while a different participant reported that it felt unethical to answer questions about other countries (thus decided to leave those questions blank). A few stakeholders commented that the questionnaire was quite long (participants were informed that the questionnaire would take approximately 15 minutes to finish).

Based on such comments, a better approach could have been to develop questionnaires that were specifically aimed at certain groups of stakeholder. However, most questions were considered applicable across a range of stakeholders, and it was considered relatively labour and time intensive to create a specific questionnaire for each group. Such an approach would also have further complicated the statistical analysis (e.g. in terms of collapsing and interpreting the data). It could have proved advantageous to include more – or replaced – some questions with open-ended ones, as this could reduce the feeling of being restricted or guided in a certain direction by the limited number of response alternatives. That being said, participants did have the opportunity to add additional comments throughout, as well as in the final section of the questionnaire (i.e. “provide general views or comments about GM crops”). A different approach could have been to complement the questionnaires with focus groups or some form of workshop(s), though such an approach was not considered feasible as already noted.

Finally, it is likely that stakeholders would have found it easier to dedicate the time if the questionnaire was shorter and/or a survey tool such as SurveyMonkey has been employed (i.e. whereby the questionnaire can be filled out directly, as opposed to having to download a pdf/word-file, fill it out and return it via email).

25.3. Comments valid for both the Farmer and Stakeholder surveys

25.3.1. Premature inclusion of Ethiopia and Tanzania?

One could argue that perception studies are not timely in countries such as Ethiopia and Tanzania, whereby the awareness of biotechnology is currently relatively low, especially among rural farmers. Thus, by postponing the survey in the selected countries with a few years, it would have allow more time for people to get acquainted with the topic of biotech crops and the tangible evidence. Still, it was decided to include respondents from all study countries for the stakeholder survey. The decision was based on the idea that there would be a sufficient number of respondents (though this might not have been a correct assumption, as discussed in section 25.2.1 and 25.2.2), and that the information obtained would be of particular interest considering the recent regulatory amendments in Tanzania and Ethiopia. For the farmer surveys on the other hand, it was determined to exclude Ethiopia as the level of awareness was considered insufficient. After discussing the matter with agricultural economists and other Tanzanian stakeholders, it was decided to proceed with the farmer survey in Tanzania.

25.3.2. Too broad scope of study countries?

By focusing on a single or fewer number of study countries, it could have allowed for a more thorough understanding of the GMO debate, as well as the historical, cultural, socio-economic and socio-political conditions of the country in question. However, the thesis set out to investigate the current changing climate surrounding the GMO debate in East Africa, thus it was desirable to include all countries in which regulatory frameworks were in place or were being developed. Information from such comparative studies can be important guiding R&D, risk-communication, awareness and capacity building, regional harmonisation efforts, and so forth.

25.5.4. Concluding remarks

Farmer surveys. For the farmer surveys, the study design (i.e. non-randomly selected and non-representative sampling, and having to deal with group-level data) confounded the ability to generalise findings and further required a specifically designed simulation model to be employed. Some of the issues related to the study design could have been limited or avoided if more knowledge on the conduction of perception studies had been acquired prior to the study. However, the study made use of the best available data given constraints dictated by time, budget, travel opportunities and safety. Finally, the experience has shown the impact that differences in agro-ecological, climatic and infrastructural conditions, and cultural norms and socio-economic aspects (e.g. lack of human and infrastructural resources, power and internet connection, and outbreak of disease and drought), can have, as well as the importance of proper communication and personal participation.

Stakeholder survey. The topic of GMOs is a complicated one, which makes it challenging to phrase questions in a specific and relatively simple manner, as well as employing neutral formulations. Though the majority of participants made no comment on the framing of the questions, some did perceive it as subjective or non-applicable for the general stakeholder. In this respect, more open-ended questions and/or developing questionnaires aimed at a specific group of stakeholders could have proved advantageous. Additionally, it could have been useful to shorten the questionnaire, as the mere length could have discouraged certain participants.

In terms of the execution, people at top positions or key informants should have been identified earlier as a way of aiding in the distribution and implementation of the questionnaire. Furthermore, it could have proved useful to employ a tool like SurveyMonkey as opposed to administering a soft copy of the questionnaire via email. Additionally, arranging focus groups or workshops in conjunction with or in the aftermath of the survey could have complemented the questionnaire (i.e. provide more qualitative data) and helped build trust. However, given constraints dictated by budget, time and travel opportunities, this approach was not feasible. Finally, the lack of a representative number of participants from all stakeholder groups, as well as the non-randomly selected data, required a specifically designed simulation model to be employed and further challenged the ability to apply and generalise findings in a wider context.

Part F. Recommendations and Overall Conclusions

Chapter 26. Recommendations: How can Biotech Crops Best be Implemented in the East African Society?

Based on what has been learnt through the literature review, results obtained from the perception studies, and knowledge acquired during interviews and laboratory work, a series of recommendations for the further development of the agricultural sector and the potential implementation of biotech crops in East Africa can be made. However, these are general recommendations and their applicability may vary according to the transgenic crop variety, socio-economic factors, the socio-political climate, and/or on the geographical and environmental conditions in question.

1) **Regulatory frameworks and policies should be designed in a way that are effective enough to minimise the potential risks of biotech crops, while still facilitating R&D, in order to deliver the maximum benefits to farmers and society.** A sound and trustworthy legal system should be transparent, adaptable, robust, scientifically-sound and participatory. Furthermore, socio-economic considerations can be made part of regulatory decision-making, but should be done in a way which avoids unnecessary and additional costs that may otherwise limit the uptake of approved technologies.
2) **Local public and private institutions and companies should take greater and more active part in the development of pro-poor and situation-specific biotech crops using local germplasm for optimal adaptation, and subsequently introduce these via national extension services**. Governments need to engage the public and private sector by providing incentives and increasing governmental expenditure. Furthermore, by introducing varieties locally, it will help remove the feeling that the technology is being imposed by foreign investors and agribusinesses.
3) **Private multinationals should aim for long-term commitment in agri-biotech projects and PPPs which employ a bottom-up approach that keeps the best interest of the farmers in mind.** This will require developing local skillsets in negotiating (royalty-free) technology access and managing IPR issues, as well as creating incentives for multinationals to employ their expertise, donate technology and extend funding in a market where the financial returns may be relatively small.
4) **Work closely with and engage farmers and the public in the development, dissemination and debate on biotech crops.** Hitherto, many research projects have been poorly connected to farmers and the public, especially the rural poor and marginalised groups. By involving the public and farmers, it will facilitate trust and transparency; enhance public and farmer understanding and demand; and help researchers, regulatory decision-makers and policymakers to better identify the needs and concerns of farmers and potential SECs and obstacles to adoption. This will require giving voice to, empower and educate farmers and politically weaker groups (e.g. women) through governmental policies and awareness and educational campaigns. For the latter, civil society and NGOs in which farmers display a high

degree of trust, as well as the media, can represent valuable channels of information *if* done in an unbiased and factual manner.

5) **Protect and promote Farmers' Rights.** Governments, policymakers and civil society groups need to address issues concerning, amongst others, inequitable distribution of land, insecure land tenure, poor access to credit and input/output markets, and unequal allocation of subsidies.
6) **Promote capacity building and improve communication between all stakeholders involved in the field of agricultural biotechnology.** Capacity building initiatives should be aimed at all stakeholders, including farmers, the media, researchers, regulators, policymakers, extension workers, the industry, civil society and non-governmental groups, and so forth. Furthermore, improved communication between such stakeholders should be promoted, both locally and across borders, as a way of facilitating best experience and practice, building trust, reducing the polarisation of the debate, and to establish clear guidelines and policies governing biosafety and biotechnology.
7) **Introduce biotech crops along-side conventional varieties, agro-ecological and organic farming, and good agricultural practices.** Biotech crops are a complimentary tool that should be compared to other alternatives and possible paths of action (including inaction). If implemented, the technology should work concurrently with traditional breeding efforts and the introduction of other improved varieties (e.g. hybrid seeds), improved tool use and mechanisation, good agricultural practices (e.g. weeding and crop rotation), better irrigation systems and water management, and increased agricultural inputs (e.g. fertilisers).
8) **The international community should allow for a neutral space in which the East African governments can make their own informed decision on the topic of GM crops, and rather make contributions towards infrastructural, technical, institutional and scientific capacity. Regional harmonisation efforts** of biotechnology and biosafety policies and projects could help promote capacity building; pooling and sharing of scientific, technical and regulatory expertise and resources; facilitate trade and commerce; and promote the East African region as a bigger and more lucrative market for investors and developers.
9) **Development of other sectors, including infrastructure, science & education, and health.** The full potential of biotechnology may not be realised without sufficient and adequate road systems, storage, irrigation systems, markets and research facilities. Furthermore, if the root of hunger and poverty is not targeted, then food insecurity will continue to persist regardless of whether or not GM crops are introduced. Indeed, several factors contribute to food insecurity in Africa, including social, cultural, infrastructural, economic and political issues. An emphasis should be made on combating gender inequalities, corruption, war & conflict, HIV/AIDS and other health concerns, and improving infrastructure and educational efforts.

Chapter 27. Overall Conclusions

The aim of this thesis was to investigate the role that biotech crops could play in addressing some of the challenges faced by the East African society, as well as the many considerations that may have to be deliberated in conjunction with the potential introduction of the technology. Pro-poor and situation-specific biotech crops that address the needs, cultural preferences and traditional practices of the East African farmer appear to be an attractive complimentary tool for the development of the agricultural sector, especially in the face of climate and environmental change. For instance, BXW-resistant bananas may provide a solution for the millions of farmers whose income and livelihood is threatened by this devastating disease, particularly considering the limitations of conventional breeding using this species.

However, biotech crops are not a panacea and should be introduced alongside conventional breeding techniques and agro-ecological and organic farming; good agricultural practices; better access to inputs (e.g. fertilisers), credit and markets; improved irrigation and management of water resources; better tools and mechanisations; and development of other sectors such as infrastructure, health and education.

Furthermore, there are several potential barriers to the widespread adoption of biotech crops, many of which were identified through the literature review and from the results of the perception surveys. For instance, the political climate has been avoid of a neutral space in which African governments can make their own informed decisions, which appear to have constrained the adoption of new technology and led to contradictory attitudes of many regulatory decision and policymakers. However, recent regulatory amendments in Tanzania and Ethiopia indicate a more unified political will to further develop the agri-biotechnology sector. Furthermore, despite the apparent sluggish process, the approval of the environmental release of Bt cotton and WEMA maize in Kenya can be considered a significant step towards commercialisation. Finally, Uganda may or may not decide to pass the Biotechnology and Biosafety Bill into law, but have shown that a legally instated biosafety framework does not necessarily constrain R&D.

Furthermore, there are a number of infrastructural, environmental and socio-economic considerations associated with the introduction of biotech crops, which further underlines the need of carrying out the debate on – and application of – biotechnology within a framework characterised by responsibility, control and a respect for humans and the environment. However, it would be unfortunate if concerns which appear to be largely unjustified (e.g. potential loss of trade to the EU and health scares like cancer) undermined the adoption of a potentially advantageous technology, while other aspects do require more careful consideration (e.g. potential impacts on Farmers' Rights; lack of scientific, technical, regulatory, institutional and infrastructural capacity; and long-term ecological effects). However, it is also important to factor in the potential positive socio-economic and environmental effects of biotech crops during regulatory decision-making. Consequently, it is essential that the regulatory framework is characterised by transparency, robustness and adaptability, as well as being scientifically-sound, testable, participatory, inclusive, and time and cost-effective.

In the end, it all boils down to whether biotech crops are something that the East African farmer and consumer wants; it is for them the technology mainly will affect the livelihoods of, and the decision on whether or not to adopt a GM crop variety ultimately lies in their hands. After all, the smallholder farmer represents the backbone of the economy, and if not the most essential part of the East African society. According to the findings from the present thesis, the majority of Kenyan, Ugandan and Tanzanian farmers do consider biotech crops as an attractive tool that they wish to adopt in their farming life. Still, many expressed concerns associated with the technology, which needs careful consideration by civil society organisations, developers, researchers and policy and decision-makers. Additionally, the low level of awareness and knowledge of biotech crops in certain farming communities underlines the importance of implementing awareness and educational efforts. Encouragingly, if there is one thing that the farmer surveys have shown, it is the ability, eagerness and willingness of farmers to learn more about the technology at hand, and the aspiration of overcoming traditional isolation by employing useful, available and affordable technologies.

As a final remark, as we step into an area of genome editing – which allows for precise and targeted alterations of the genome of more or less any species (see e.g. Wang *et al*., 2016) – one could ask oneself what role transgenics will play in the foreseeable future. Indeed, as many East African governments are left discussing whether or not to adopt biotech crops, the rest of the world appears to be moving on. Will this be the time when African countries step up to the plate and move on from the political attitudes and at times "invisible" forces which have previously kept the continent out of the loop – some of which appear to have emanated from the Western world – in order to keep up with the global development and to steer the agricultural sector in a direction which will benefit the African farmer and society the most?

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Appendices

Feeding East Africa: Can genetically modified crops be part of the solution?

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Appendices 1. Social Sciences Study

Appendix A. Farmer questionnaire

Farmers' Perceptions Survey Questionnaire on Biosafety Laws and Regulations Governing the Commercialization, Production and Consumption of Genetically Modified Crops in East Africa

The purpose of this survey is to understand the attitude of East African farmers towards commercialization, production and consumption of Genetically Modified crops. The survey is organized by the Biotechnology Department of the Norwegian University of Life Sciences (NMBU) in collaboration with the International Institute of Tropical Agriculture (IITA).

In the context of this questionnaire, Genetically Modified Crops are defined here as plants modified by genetic engineering technique to enhance desired characteristics such as high yielding capacity, increased resistance to drought, diseases, and pests.

General

Which of the following are challenging to your farming? (Tick one per row)

Constraints	Not challenging at all	Somewhat challenging	Challenging	Very challenging
Low crop productivity and yield				
Poor quality of produce				
Incidence of crop pest and diseases				
Post-harvest losses				
Climate change (drought, floods)				
Inadequate extension services				
Inadequate credit services (unable to afford inputs)				
Lack of irrigation systems				
Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)				
Poor infrastructure for market access (roads, communication)				
Debt (e.g. from having to buy inputs at high price and sell output at low prices)				
Lack of secure land tenure and property rights				
Land degradation				
Spending too much time in the field (i.e. insufficient time for other activities)				
Other (please specify):				

Module A: GMO – Awareness, impression, interest, desirable traits, perceived concerns, farmers' attitude towards GM crops and support for GM crop commercialization

Are you aware of GM crops?

Aware of GM crops?	Response
Yes	
No	

If yes, what is your impression of GM crops?

Impression	Response
Favorable	
Unfavorable	

Would you grow GM crops if you had the opportunity?

	Response	
Yes		
No		**If no, why not?**

If yes, what do you look for in GMO crops? (Please select yes or no)

Desirable traits	Yes	No
Drought-tolerance		
Pest- and disease tolerance		
Increased yield		
Improved nitrogen-use efficiency		
Enhanced storage capacity		
Higher nutritional value and quality		
Other (please specify):		

What concerns do you have regarding GM crops?

Concerns	Not concerned at all	Somewhat concerned	concerned	Very concerned
Negative health effects (e.g. allerginicity/toxicity)				
Negative environmental effects (e.g. loss of traditional varieties and genetic diversity due to GM "contamination" with indigenous varieties, increased use of herbicides and pesticides due to resistance development by pests and pathogens because of cross pollination between GM crops and				

conventional crops/weeds)				
Religious/cultural concerns - sourcing of genes from culturally or religiously unacceptable organisms				
Intellectual property rights protection for seeds companies and loss of farmer's rights (e.g. loss of control over re-use of seeds)				
Consumer reluctance to buy GM products and hence loss of income				
Low profitability and hence increased debt				
Other (please specify)				

Does having to buy good quality seeds every season from the seed company concern you?

	Response
Yes	
No	

What do you think is the attitude of the majority of farmers in your area towards GMOs?

Attitude	Response
Favorable	
Unfavorable	
No opinion	

How influential is your religious beliefs on your consumer acceptance of GM foods (please tick)?

	Response
Not influential at all	
Somewhat influential	
Influential	
Very influential	

Where do you gather/receive information about GM crops? (Please select yes or no per row)

Source of information	Yes	No
The media		
Statements of governmental officials		
Researchers / extension		
Non-governmental organisations		
Seed/input companies		
Other (please specify):		

Do you believe GM crops could help improve the quality of life of farmers in your country?

	Response	
Yes		

No		**If no, why not?**
No opinion		

Do positive results obtained from countries such as Burkina Faso (whereby planting of Bt Cotton has led to an average increase in yield of almost 20 %, a reduction in pesticide-use of ~67 %, and a 51 % increase in income levels compared to conventional cotton) – make you want do demand such crops yourself?

	Response
Yes	
No	
No opinion	

Do you support the approval of the commercialization of GM crops?

	Response
Yes	
No	
No opinion	

Module B: Demographic/socioeconomic questions

What is your sex?

Gender	Response
Male	
Female	

What is your age?

Age (years)	Response

Which best describes your level of formal education?

Level of education	Response
Primary school	
Secondary school	
Some college	
Completed University/College at Bachelor level	
Completed University/College at Master level	
University/College at PhD level	
Other(specify)	

What is your marriage status?

Marriage status	Response
Single	
Married	

Which best describes your farm size in hectare?

Farm size	Response
Less than 0.5 ha	
0.5-0.9 ha	
1.0-1.9 ha	
2.0-2.9 ha	
3.0-3.9 ha	
4.0-4.9 ha	
Above 5 ha (please specify)	

What is your religion?

Religion	Response
Muslim	
Christian	
Other (please specify)	

How best do you describe yourself culturally?

Cultural leaning	Response
Liberal	
Moderate	
Conservative	

What is your nationality?

Nationality	Response
Kenyan	
Ugandan	
Tanzanian	
Ethiopian	
Other (please specify)	

Please provide general views or comments about GM crops

Appendix B. Stakeholder questionnaire: Public Perceptions Survey Questionnaire on Biosafety Laws and Regulations Governing the Commercialization, Production and Consumption of Genetically Modified Crops in East Africa

Project background and aim: The purpose of this survey is to understand the attitude of policy makers, agricultural researchers, extension workers, farmers and development practitioners in private, public and non-governmental institutions towards commercialization, production and consumption of Genetically Modified (GM) crops*. Consequently, participants for the study are picked on the basis of their involvement in the topic of GM crops in their respective country or the East African region.

The survey is organized by the Biotechnology Department of the Norwegian University of Life Sciences (NMBU) in collaboration with the International Institute of Tropical Agriculture (IIT**A)**. The data obtained will be used as part of the master thesis “Laws, Regulations and Public Perception of Genetically Modified Crops in East Africa”.

Data collection: data will be collected via a questionnaire sent and returned via email. The questionnaire includes questions concerning awareness and general opinions of GM crops in the participant’s country and East Africa. The final section will collect demographic information on the study participant. The data will be registered in the form of a written word document.

Voluntary participation: Participation is anonymous and voluntary. Participants can withdraw from the study up until the study concludes without having to provide any reason for doing so (the project is anticipated to conclude on 1st of May 2017). All information will be treated confidentially. Information will be stored in definitively after the completion of the study, and can be accessed by the project group (including the relevant people at the Norwegian University of Life Sciences and IITA).

If you have any questions regarding the study, please contact:
Master student:
Ida Arff Tarjem
idaarff@gmail.com
+47 95804384
Supervisor:
Trine Hvoslef-Eide
Trine.hvoslef-eide@nmbu.no
+47 93433775

Please tick: I have read and understood the information given above and agree to participate in the study.

I agree	I do not agree

(Signature and date)
General

How important are the following challenges in affecting the agricultural sector in your country? (Please tick per row)

Challenges	Not important at all	Somewhat important	Important	Very important
Low crop productivity and yield				
Incidence of crop pest and diseases				
Climate change (drought, floods)				
Inadequate extension services				
Inadequate credit services				
Lack of irrigation systems				
Lack of improved agricultural technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)				
Low adoption rate of improved technologies				
Poor infrastructure for market access (roads, communication)				
Lack of secure land tenure and property rights				
Misguided agricultural policies				
Land degradation				
Youth attitude towards farming				
Other (specify)				

Module A: GMO – Awareness, views, role, perceived benefits, perceived concerns, barriers, measures, trends in attitude towards GM crops

Are you aware of GM crops? Please tick.

	Response
Yes	
No	

If yes, what is your view regarding commercialization of GM crops in your country? (Please tick per row for each crop type)

Crops	Strongly unfavorable	Somewhat favorable	Favorable	Strongly favorable
GM food crops (example Bt maize)				
GM cash crops (example Bt cotton)				

How much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country? (Please tick per row)

Strongly disagree	Somewhat agree	Agree	Strongly agree	No opinion

How much do you agree or disagree that efforts being made to commercialize GM crops in East Africa are not wise a timely: conventional measures (e.g. conventional breeding, increased use of fertilizers, improved crop management better irrigation systems, improved mechanization and tools) should be first fully exploited before embarking on use biotechnology? (tick per row)

Strongly disagree	Somewhat agree	Agree	Strongly agree	No opinion

How much do you agree or disagree that East Africa countries are not ready yet for GMOs: They should first develop their regulatory capacity and improve their infrastructure (regulatory capacity, roads, markets, storage space, irrigation systems, research institutions) before they adopt GMOs?

Strongly disagree	Somewhat agree	Agree	Strongly agree	No opinion

If any, please indicate the level of your concerns about commercialization of GM crops in your country (please tick pe row)?

Concerns	Not concerned at all	Somewhat concerned	concerned	Very concerned	No opinion
Negative health effects (e.g. allerginicity/toxicity)					
Negative environmental effects (e.g. genetic pollution, loss of genetic diversity due to contamination with indigenous crops, increased use of herbicides and pesticides)					
Development of resistance by pests and pathogens, including ”superweeds”, because of cross pollination between GM crops and conventional crops/weeds					
Religious/cultural concerns - sourcing of genes from culturally or religiously unacceptable organisms					
Damage relationships with neighboring countries who oppose GM crop					

commercialization					
Damage relationship & loss of trade with E.U. which is not in favor of GMOs					
Socio-economic reasons (e.g. widening income gaps)					
Alter social structure (i.e., patterns of relationships between different groups, e.g., men are benefiting more than women and hence causing gender inequality)					
Other (please specify)					

Which of the following are important barriers to the adoption of GM crops in your country? (tick per row)

Barriers	Not important at all	Somewhat important	Important	Very important	I don't know
Lack of political will					
Misinformation and misperception among the public and farmers					
Consumer distrust					
Weak public/farmer demands and reluctance					
Lack of technical, human and infrastructural capacity					
Weak, inefficient, contradictory attitudes of regulatory bodies					
Inadequate donor funding					
Concern of damaging relationship with the E.U.					
Concern of damaging relationship with non-GM adopting neighboring countries					
Trade concerns and loss of market access					
Lobbying by anti-GM advocates					
Polarized debate presented in the media					
Other (please specify)					

How important are following measures for the successful adoption of GM crops in your country (tick per row) ?

Measures	Not important at all	Somewhat important	Important	Very important	I don't know
Supporting research in the domestic public as opposed to private multinational biotechnology companies					
Increased awareness of farmers and the public; farmer and public demand					
Increased political will					
Science-based regulatory systems					
Increased human and infrastructural capacity					
Capacity-building programs; private-public partnerships					
Less interference from international community					
Increased interference from international community					
Opening up trade barriers					
Objective and factual media coverage					
Royalty-free seeds					
Non-polarized debate among pro- and anti-GM advocates					
Other (please specify):					

How likely are the following changes to occur as a result of adoption of GM crops in your country?

Changes	Not likely at all	Somewhat likely	Likely	Very likely	I don't know
Local smallholder farmers' rights are negatively affected					
Women are negatively affected (gender inequality)					
Concentration of power and capital in commercial farms					
Increased income gap between the rich and the poor farmers					
Others (please specify)					

Module C: East African Government GMO laws, pending legislations and regulations

In your opinion, how do you think your government's attitude towards commercialization of GMOs has changed over the last few years?

Trend in government's attitude	Yes	No	I don't know
The government has become more favorable towards GM crops in recent years			
The government has become less favorable towards GM crops in recent years			

If you think that there has been a change in favor of GM crops, how likely are the following explanations to be true for this attitude change?

Possible reasons	Not likely	Somewhat likely	likely	Very likely	I don't know
Pressure from pro-GM advocates					
Positive results obtained from GM-adopting countries (e.g. Burkina Faso, Sudan, India)					
Prospect of climate change					
Pressure from the scientific community					
Consumer and farmer demand					
Other (please specify):					

If you think there has been a change in less favour of GM crops, how likely are the following to be true in explaining the lack of political will?

Reasons	Not likely	Somewhat likely	likely	Very likely	I don't know
Pressure from anti-GMO groups					
Genuine concerns and fear of potential health effects					
Genuine concerns and fear of potential environmental effects					
Do not really perceive GM crops as beneficial					
The technology and approval process is considered too expensive compared to the end profit					
Fear of losing market access and due to political economy					
Fear of socio-economic and socio-political implications					
Inadequate farmer and public demand					
Fear of politicians losing votes in the next election					
Other (please specify):					

How do you think the public's attitude towards commercialization of GMOs has changed over the last few years?

	Yes	No	I don't know
The public has become more favorable towards GMOs in recent years			
The public has become less favorable towards GMOs in recent years			

How likely is your country in approving the commercialization of GM crops in the next few years?

Not likely at all	Somewhat likely	Likely	Very likely	Has already approved

Are you aware that the Kenyan government enacted the Biosafety Bill of 2009 aimed at ensuring and assuring safe development, transfer, handling and use of genetically modified organisms in Kenya?

	Response
Yes	
No	

What do you think of this Act?

	Response
Wise and timely decision	
Unwise and untimely decision	
Other (specify)	

Do you think that the Kenyan Biosafety Act would influence other African countries to follow suit? (Please tick yes or no)

	Response
Yes	
No	

Do you support the lifting of the 2012 ban on the importation of GM food in Kenya?

	Response	
Yes		
No		If no, why?

Do you support the passage of the biosafety bill into law in Uganda?

	Response	
Yes		
No		If no, why?

Do you support the Tanzanian's government's intention of revising the current regulatory framework to allow for confined field trials and ultimately commercialization?

Response	Response	
Yes		
No		If no, why?

Do you support the amendments made to the Biosafety Proclamation in Ethiopia that is meant to facilitate commercialization of GM crops?

Response	Response	
Yes		
No		If no, why?

How much do you agree or disagree that East African countries should strive for a regional harmonization of biosafety regulations and policies?

Strongly disagree	Somewhat agree	Agree	Strongly agree	No opinion

If yes, which benefits are likely to be realized through such harmonization?

Benefits	Not likely	Somewhat likely	likely	Very likely	I don't know
Transfer of technologies and policies					
Ease of trade and enhanced commerce					
Facilitate capacity-building and sharing of experiences					
Mitigate negative trade effects					
Greater regulatory efficiency, and simplify the approval process.					
Other (please specify):					

Module D: International Support for GM crops

Do you think that it is appropriate for the international community to promote use of GM crops as solution for poverty problem in Africa?

	Response
Yes	
No	

How do you think the international community should support East African countries to advance their agricultural biotechnology sector?

Ways of support	Yes	No
Assist them develop their own public biotechnology research program		
Initiate public-private partnerships with multinational biotech companies for technology-sharing		
Aid in developing laws, legislations and policies concerning biosafety and biotechnology		
Awareness campaigns		
Other (please specify):		

Module D: Communication

What do think of the way GMO assessment is communicated to the public in your country? Is it balanced or biased towards the positive side of the GMOs?

GMO assessment	Response
Biased towards the positive side	
Biased towards the negative side	
Balanced	
I don't know	

Which of the following issues are likely to inspire controversy among the public in East your country (tick per row)?

Issues	Not likely at all	Somewhat likely	Likely	Highly likely
Potential health concerns (e.g. allerginicity, toxicity, carcinogenicity, sterility and obesity)				
Environmental effects (e.g. loss of biodiversity and non-target effects)				
Religious and cultural implications (e.g. "man playing god", sourcing genes from "unclean" species); negative effects on highly valued cultural crops				
Loss of farmer's rights and decision-making fall under the complete control of the biotech companies				
Damage of relationships to neighbouring countries				
Damage of relationships to the E.U. or other Great Powers				
Loss of market (e.g. to the E.U.)				
What is claimed to be achieved through GM can also be achieved through conventional means				

Other (please specify):	

Which of the following measures are likely to correct some of the common misconceptions about GMOs in your country?

Measures	Not likely at all	Somewhat likely	Likely	Highly likely
Awareness campaigns				
More factual and objective media coverage				
Stronger and clearer guidelines from the government				
Stronger voice of the scientific community				
Other (please specify):				

How influential are the anti-GM groups in swaying public and farmers' opinion of GMOs?

Level of influence	Response
Highly influential	
Moderately influential	
Low influence	
No influence	
No opinion	

Module E: Consumption

Do you pay attention to labels for food products as you buy food from the super markets?

	Response
Yes	
No	

If yes, do you check whether it has GMO content or not?

	Response
Yes	
No	

Do you support for strict regulations and labeling in food products in your country?

	Response
Yes	
No	

Do you support importation and sale of food products with GM contents in your country?

	Response
Yes	
No	

Have you ever consumed food containing GMOs?

	Response
Yes	
No	
I don't know	

If no, would you be willing to consume foods containing GM products?

	Response
Yes	
No	

How influential is your religious beliefs on your consumer acceptance of GM foods (please tick)?

	Response
Not influential at all	
Somewhat influential	
Influential	
Very influential	

Module F: Demographic/socioeconomic Characteristics

What is your sex?

Gender	Response
Male	
Female	

What is your age?

Age (years)	Response

Which best describes your level of formal education?

Level of education	Response
Primary school	
Secondary school	
Some college	
Completed University/College at Bachelor level	
Completed University/College at Master level	
University/College at PhD level	

Other(specify)	

What is your marriage status?

Marriage status	Response
Single	
Married	

Which best describes your monthly income in US $?

Income level	Response
Less than US$ 200	
US $200-399	
US $400-599	
US $600-799	
US $800-999	
US $1000 or more	

What is your religion?

Religion	Response
Muslim	
Christian	
Other (please specify)	

What is your nationality?

Nationality	Response
Kenyan	
Ugandan	
Tanzanian	
Ethiopian	
Other (please specify)	

What is your family background?

Family background	Response
Farm family	
Non-farm family	

Where did you grow up?

Location	Response
Rural village	
Small town	
City	

How best do you describe your knowledge of agriculture and rural life?

Knowledge level	Response
Not much	
Know enough	
Very knowledgeable	

How best do you describe yourself culturally?

Cultural leaning	Response
Liberal	
Moderate	
Conservative	

Which best describes your primary occupation?

Occupation	Response
Farmer	
Agricultural researcher	
Agricultural extension personnel	
Policy maker (legislator, regulator at federal, regional, district and municipal levels)	
A civil servant employed in the private/public sector related to agriculture	
A civil servant in employed in the private/public sector NOT related to agriculture	
A civil servant in a non-governmental organization sector	
Other(specify)	

Please provide general views or comments about GM crops

Appendix C. Variable Definition and Coding

C.1. Variable Definition and Coding for Farmers questionnaire

Table C.1. Variable Definition and Coding for Farmers-questionnaire.		
Variable/Category	**Definition**	**Coding**
General		
Challenges (G)	Which of the following are challenging to your farming?	a = not important at all; b= somewhat important; c = important; d =very important
G1 [a/b/c/d]	Low crop productivity and yield	No. of farmers for a/b/c/d respectively
G2 [a/b/c/d]	Poor quality of produce	No. of farmers for a/b/c/d respectively
G3 [a/b/c/d]	Incidence of crop pest and diseases	No. of farmers for a/b/c/d respectively
G4 [a/b/c/d]	Post-harvest losses	No. of farmers for a/b/c/d respectively
G5 [a/b/c/d]	Climate change (drought, floods)	No. of farmers for a/b/c/d respectively
G6 [a/b/c/d]	Inadequate extension services	No. of farmers for a/b/c/d respectively
G7 [a/b/c/d]	Inadequate credit services (unable to afford inputs)	No. of farmers for a/b/c/d respectively
G8 [a/b/c/d]	Lack of irrigation systems	No. of farmers for a/b/c/d respectively
G9 [a/b/c/d]	Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	No. of farmers for a/b/c/d respectively
G10 [a/b/c/d]	Poor infrastructure for market access (roads, communication)	No. of farmers for a/b/c/d respectively
G11 [a/b/c/d]	Debt (e.g. from having to buy inputs at high price and sell output at low prices)	No. of farmers for a/b/c/d respectively
G12 [a/b/c/d]	Lack of secure land tenure and property rights	No. of farmers for a/b/c/d respectively
G13 [a/b/c/d]	Land degradation	No. of farmers for a/b/c/d respectively
G14 [a/b/c/d]	Spending too much time in the field (i.e. insufficient time for other activities)	No. of farmers for a/b/c/d respectively
Awareness		
GMAw	Are you aware of GM crops?	GMAw1 = no. of aware farmers; GMAw2 = no. of unaware farmers
Attitude and perceptions		
GMFav	If aware, what is your impression of GM crops?	GMFav1 = favourable; GMFav2 = unfavourable; GMFav3 = do not know
GMGr	Would you grow GM crops if you had the opportunity?	GMGr1 = would grow; GMGr2 = would not grow; GMGr3 = do not know
GMTr	If yes, what do you look for in GMO	Number of respondents

	crops?	answering “yes” recorded for each
GMTr1	Drought-tolerance	No. of farmers
GMTr2	Pest- and disease tolerance	No. of farmers
GMTr3	Increased yield	No. of farmers
GMTr4	Improved nitrogen-use efficiency	No. of farmers
GMTr5	Enhanced storage capacity	No. of farmers
GMTr6	Higher nutritional value and quality	No. of farmers
FrmAtt	What do you think is the attitude of the majority of farmers in your area towards GMOs?	FrmAtt1 = favourable; FrmAtt2 = unfavourable; FrmAtt3 = I do not know
RlgInf	How influential is your religious beliefs on your consumer acceptance of GM foods?	RlgInf1 = not important at all; RlgInf2 = somewhat important; RlgInf3 = important; RlgInf4 = very important
QtlImp	Do you believe GM crops could help improve the quality of life of farmers in your country?	QtlImp1 = yes; QtlImp2 = no; QtlImp3 = no opinion
GMCom	Do you support the approval of the commercialization of GM crops?	GMCom1 = yes; GMCom2 = no; GMCom3 = do not know
Concerns		
A5	What concerns do you have regarding GM crops?	a = not concerned at all; b= somewhat concerned; c = concerned; d =very concerned
A5.1 [a/b/c/d]	Negative health effects (e.g. allerginicity/toxicity)	No. of farmers for a/b/c/d respectively
A5.2 [a/b/c/d]	Negative environmental effects (e.g. loss of traditional varieties and genetic diversity due to GM "contamination" with indigenous varieties, increased use of herbicides and pesticides due to resistance development by pests and pathogens because of cross pollination between GM crops and conventional crops/weeds)	No. of farmers for a/b/c/d respectively
A5.3 [a/b/c/d]	Religious/cultural concerns - sourcing of genes from culturally or religiously unacceptable organisms	No. of farmers for a/b/c/d respectively
A5.4 [a/b/c/d]	Intellectual property rights protection for seeds companies and loss of farmer's rights (e.g. loss of control over re-use of seeds)	No. of farmers for a/b/c/d respectively
A5.5 [a/b/c/d]	Consumer reluctance to buy GM products and hence loss of income	No. of farmers for a/b/c/d respectively
A5.6 [a/b/c/d]	Low profitability and hence increased debt	No. of farmers for a/b/c/d respectively
Seeds	Does having to buy good quality seeds every season from the seed company concern you?	Seeds1 = yes; Seeds2 = no
Information		

Inf	Where do you gather/receive information about GM crops?	Number of respondents answering "yes" recorded for each
Inf1	The media	No. of farmers
Inf2	Statements of governmental officials	No. of farmers
Inf3	Researchers / extension	No. of farmers
Inf4	Non-governmental organisations	No. of farmers
Inf5	Seed/input companies	No. of farmers
Brkfas	Do positive results obtained from countries such as Burkina Faso (whereby planting of Bt Cotton has led to an average increase in yield of almost 20 %, a reduction in pesticide-use of ~67 %, and a 51 % increase in income levels compared to conventional cotton) – make you want do demand such crops yourself?	BrkFas1 = yes; BrkFas2 = no; BrkFas3 = no opinion
Demographics		
Gender	What is your sex?	
B1a	Female	Number of female farmers
B1b	Males	Number of male farmer
Age (years)	What is your age?	
B2a		Age interval of farmers
Level of Education	Which best describes your level of formal education?	
B3	Primary school	Number of farmers with primary school education
B4a	Secondary school	Number of farmers with secondary education
B4b-B4e	Higher education	Number of farmers with higher education (incl. "some college", bachelor, master and Ph**D)**
NoEd	No education	Number of farmers with no education
Marriage status	What is your marriage status?	
B5a	Single	Number of single farmers
B5b	Married	Number of married farmers
Farm size	Which best describes your farm size in hectare?	
B6a	Less than 0.5 ha	Number of farmers with a farm size less than 0.5 ha
B6b	0.5-0.9 ha	Number of farmers with a farm size less 0.5-0.9 ha
B6c	1.0-1.9 ha	Number of farmers with a farm size 1.0-1.9 ha
B6d	2.0-2.9 ha	Number of farmers with a farm

		size 2.0-2.9 ha
B6e	3.0-3.9 ha	Number of farmers with a farm size 3.0-3.9 ha
B6f	4.0-4.9 ha	Number of farmers with a farm size 4.0-4.9 ha
B6g	Above 5 ha	Number of farmers with a farm size above 5 ha
Religion	What is your religion?	
B7a	Christian	Number of farmers that are Christian
B7b	Muslim	Number of farmers that are Muslim
B7c	Other	Number of farmers that have other religious beliefs
Cultural leaning	How best do you describe yourself culturally?	
B8a	Liberal	Number of farmers that consider themselves liberal culturally
B8b	Moderate	Number of farmers that consider themselves moderate culturally
B8c	Conservative	Number of farmers that consider themselves conservative culturally
Nationality	What is your nationality?	
B9a	Kenyan	Number of farmers with Kenyan nationality
B9b	Ugandan	Number of farmers with Ugandan nationality
B9c	Tanzanian	Number of farmers with Tanzanian nationality
B9d	Ethiopian	Number of farmers with Ethiopian nationality

C.2. Variable Definition and Coding for Stakeholders questionnaire

Table C.2. Variable Definition and Coding for the Stakeholders questionnaire.		
Variable/Category	**Definition**	**Coding**
General		
Challenges (Ch)	How important are the following challenges in affecting the agricultural sector in your country	0 = not important; 1 = somewhat important; 2 = important; 3 = very important
Ch1	Low crop productivity and yield	
Ch2	Incidence of crop pest and diseases	
Ch3	Climate change (drought, floods)	
Ch4	Inadequate extension services	
Ch5	Inadequate credit services	
Ch6	Lack of irrigation systems	
Ch7	Lack of improved agricultural technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	
Ch8	Low adoption rate of improved technologies	
Ch9	Poor infrastructure for market access (roads, communication)	
Ch10	Lack of secure land tenure and property rights	
Ch11	Misguided agricultural policies	
Ch12	Land degradation	
Ch13	Youth attitude towards farming	
Awareness		
GMAwa	0 if aware; 1 if not aware	0 if aware; 1 if not aware
Attitude		
GMFoodComSupp	What is your view regarding commercialization of GM food crops in your country?	0 = strongly unfavourable; 1 = somewhat favourable; 2 = favourable; 3 = strongly favourable
GMCashComSupp	What is your view regarding commercialization of GM cash crops in your country?	0 = strongly unfavourable; 1 = somewhat favourable; 2 = favourable; 3 = strongly favourable
GMRoleIss	How much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country?	0 = strongly disagree; 1 = somewhat agree; 2 = agree; 3 = strongly agree; 4 = no opinion
Perception		
ConvMea	How much do you agree or disagree that efforts being made to commercialize GM crops in East Africa are not wise and timely: conventional measures (e.g. conventional breeding, increased use of fertilizers, improved crop management ,	0 = strongly disagree; 1 = somewhat agree; 2 = agree; 3 = strongly agree; 4 = no opinion

	better irrigation systems, improved mechanization and tools) should be first fully exploited before embarking on use of biotechnology?	
ReguInfraCap	How much do you agree or disagree that East Africa countries are not ready yet for GMOs: They should first develop their regulatory capacity and improve their infrastructure (regulatory capacity, roads, markets, storage space, irrigation systems, research institutions) before they adopt GMOs?	0 = strongly disagree; 1 = somewhat agree; 2 = agree; 3 = strongly agree; 4 = no opinion
PubAttPos	How do you think the public's attitude towards commercialization of GMOs has changed over the last few years?	0 = the public has become more favourable towards GMOs in recent years; 1 = The public has become less favourable towards GMOs in recent years; 2 = I do not know
Concerns	If any, please indicate the level of your concerns about commercialization of GM crops in your country.	0 = not concerned at all; 1 = somewhat concerned; 2 = concerned; 3 = very concerned
Co1	Negative health effects (e.g. allerginicity/toxicity)	
Co2	Negative environmental effects (e.g. genetic pollution, loss of genetic diversity due to contamination with indigenous crops, increased use of herbicides and pesticides)	
Co3	Development of resistance by pests and pathogens, including "superweeds", because of cross pollination between GM crops and conventional crops/weeds	
Co4	Religious/cultural concerns - sourcing of genes from culturally or religiously unacceptable organisms	
Co5	Damage relationships with neighbouring countries who oppose GM crop commercialization	
Co6	Damage relationship & loss of trade with E.U. which is not in favour of GMOs	
Co7	Socio-economic reasons (e.g. widening income gaps)	
Co8	Alter social structure (i.e., patterns of relationships between different groups, e.g., men are benefiting more than women and hence causing gender inequality)	
Barriers (Ba)	Which of the following are important barriers to the adoption of GM crops in your country?	0 = not important at all; 1 = somewhat important; 2 = important; 3 = very important; 4

		= I do not know
Ba1	Lack of political will	
Ba2	Misinformation and misperception among the public and farmers	
Ba3	Consumer distrust	
Ba4	Weak public/farmer demands and reluctance	
Ba5	Lack of technical, human and infrastructural capacity	
Ba6	Weak, inefficient, contradictory attitudes of regulatory bodies	
Ba7	Inadequate donor funding	
Ba8	Concern of damaging relationship with the E.U.	
Ba9	Concern of damaging relationship with non-GM adopting neighboring countries	
Ba10	Trade concerns and loss of market access	
Ba11	Lobbying by anti-GM advocates	
Ba12	Polarised debate presented in the media	
Measures (Mea)	How important are following measures for the successful adoption of GM crops in your country?	0 = not important at all; 1 = somewhat important; 2 = important; 3 = very important; 4 = I do not know
Mea1	Supporting research in the domestic public as opposed to private multinationals	
Mea2	Increased awareness of farmers and the public; farmer and public demand	
Mea3	Increased political will	
Mea4	Science-based regulatory systems	
Mea5	Increased human and infrastructural capacity	
Mea6	Capacity-building programs; private-public partnerships	
Mea7	Less interference from international community	
Mea8	Increased interference from international community	
Mea9	Opening up trade barriers	
Mea10	Objective and factual media coverage	
Mea11	Royalty-free seeds	
Mea12	Non-polarized debate among pro- and anti-GM advocates	
Changes (Chg)	How likely are the following changes to occur as a result of adoption of GM crops in your country?	0 = not likely at all; 1 = somewhat likely; 2 = likely; 3 = very likely; 4 = I do not know
Chg1	Local smallholder farmers' rights are negatively affected	
Chg2	Women are negatively affected (gender	

	inequality)	
Chg3	Concentration of power and capital in commercial farms	
Chg4	Increased income gap between the rich and the poor farmers	
East African Government GMO laws, pending legislations and regulations		
GovAtt	In your opinion, how do you think your government's attitude towards commercialization of GMOs has changed over the last few years?	0 = the government has become more favourable towards GM crops in recent years; 1 = the government has become less favourable towards GM crops in recent years; 2 = I do not know
FavChg	If you think that there has been a change in favor of GM crops, how likely are the following explanations to be true for this attitude change?	0 = not likely; 1 = somewhat likely; 2 = likely; 3 = very likely; 4 = I do not know
FavChg1	Pressure from pro-GM advocates	
FavChg2	Positive results obtained from GM-adopting countries	
FavChg3	Prospect of climate change	
FavChg4	Pressure from the scientific community	
FavChg5	Consumer and farmer demand	
NegChg	If you think there has been a change in less favour of GM crops, how likely are the following to be true in explaining the lack of political will?	
NegChg1	Pressure from anti-GMO groups	
NegChg2	Genuine concerns and fear of potential health effects	
NegChg3	Genuine concerns and fear of potential environmental effects	
NegChg4	Do not really perceive GM crops as beneficial	
NegChg5	The technology and approval process is considered too expensive	
NegChg6	Fear of losing market access and due to political economy	
NegChg7	Fear of socio-economic and socio-political implications	
NegChg8	Inadequate farmer and public demand	
NegChg9	Fear of politicians losing votes in the next election	
KenBioBill	Are you aware that the Kenyan government enacted the Biosafety Bill of 2009 aimed at ensuring and assuring safe development, transfer, handling and use of genetically modified organisms in Kenya?	0 = yes; 1 = no

OpiKenAct	What do you think of this Act?	0 = wise and timely; 1 = unwise and untimely; 2 = other
InfluKenAct	Do you think that the Kenyan Biosafety Act would influence other African countries to follow suit?	0 = yes; 1 = no
GMImportBan	Do you support the lifting of the 2012 ban on the importation of GM food in Kenya?	0 = yes; 1 = no
UganBioBill	Do you support the passage of the biosafety bill into law in Uganda?	0 = yes; 1 = no; 2 = no opinion/I do not know
TanzAmend	Do you support the Tanzanian's government's intention of revising the current regulatory framework to allow for confined field trials and ultimately commercialisation?	0 = yes; 1 = no; 2 = no opinion/I do not know
EthiAmend	Do you support the amendments made to the Biosafety Proclamation in Ethiopia that is meant to facilitate commercialisation of GM crops?	0 = yes; 1 = no; 2 = no opinion/I do not know
RegHarmo	How much do you agree or disagree that East African countries should strive for a regional harmonization of biosafety regulations and policies?	0 = strongly disagree; 1 = somewhat agree; 2 = agree; 3 = strongly agree; 4 = no opinion
HarBen	If you agree that East African countries should strive for regional harmonisation, which benefits are likely to be realised through such harmonisation?	0 = not likely; 1 = somewhat likely; 2 = likely; 3 = very likely; 4 = I do not know
HarBen1	Transfer of technologies and policies?	
HarBen2	Ease of trade and enhanced commerce	
HarBen3	Facilitate capacity-building and sharing of experiences	
HarBen4	Mitigate negative trade effects	
HarBen5	Greater regulatory efficiency, and simplify the approval process	
International support		
InternSupp	Do you think that it is appropriate for the international community to promote use of GM crops as solution for poverty problem in Africa?	0 = yes; 1 = no
IntSup	How do you think the international community should support East African countries to advance their agricultural biotechnology sector?	0 = yes; 1 = no
IntSup1	Assist them develop their own public biotechnology research program	
IntSup2	Initiate PPPs with multinational biotech companies for technology-sharing	
IntSup3	Aid in developing laws, legislations and policies	

IntSup4	Awareness campaigns	
Communication		
GMMedAss	What do think of the way GMO assessment is communicated to the publicin your country? Is it balanced or biased towards the positive side of the GMOs?	0 = biased towards the positive; 1 = biased towards the negative; 2 = balanced; 3 = I do not know; 4 = balanced towards the positive and negative
Con	Which of the following issues are likely to inspire controversy among the public in your country?	0 = not likely at all; 1 = somewhat likely; 2 = likely; 3 = highly likely
Con1	Environmental effects (e.g. loss of biodiversity and non-target effects)	
Con2	Potential health concerns (e.g. allerginicity, toxicity, carcinogenicity, sterility and obesity)	
Con3	Religious and cultural implications (e.g. "man playing god", sourcing genes from "unclean" species);negative effects on highly valued cultural crops	
Con4	Loss of farmer's rights and decision-making fall under the complete control of the biotech companies	
Con5	Damage of relationships to neighbouring countries	
Con6	Damage of relationships to the E.U. or other Great Powers	
Con7	Loss of market (e.g. to the E.U.)	
Con8	What is claimed to be achieved through GM can also be achieved through conventional means	
MiscMeas	Which of the following measures are likely to correct some of the common misconceptions about GMOs in your country?	0 = not likely at all; 1 = somewhat likely; 2 = likely; 3 = highly likely
MiscMeas1	Awareness campaigns	
MiscMeas2	More factual and objective media coverage	
MiscMeas3	Stronger and clearer guidelines from the government	
MiscMeas4	Stronger voice of the scientific community	
AntiGMInflu	How influential are the anti-GM groups in swaying public and farmers’ opinion of GMOs?	0 = highly influential; 1 = moderately; 2 = low; 3 = no influence; 4 = no opinion
Consumption		
Labels	Do you pay attention to labels for food products as you buy food from the super markets?	0 = yes; 1 = no
GMcont	If yes, do you check whether it has GMO content or not?	0 = yes; 1 = no

GMRegLab	Do you support for strict regulations and labeling in food products in your country?	0 = yes; 1 = no
GMImpSale	Do you support importation and sale of food products with GM contents in your country?	0 = yes; 1 = no
GMConsume	Have you ever consumed food containing GMOs?	0 = yes; 1 = no
GMConsWilling	If no, would you be willing to consume foods containing GM products?	0 = yes; 1 = no
ReliConsAcce	How influential is your religious beliefs on your consumer acceptance of GM foods?	0 = not influential at all; 1 = somewhat influential; 2 = influential; 3 = very influential
Demographics		
Gender	What is your sex?	0 = female; 1 = male
Age	What is your age?	0 = 19-29; 1 = 30-39; 2 = 40-49; 3 = 50-59; 4 = 60-69; 5 = 70-79
Educat	Which best describes your level of formal education?	0 = primary school; 1 = secondary school; 2 = some college; 3 = completed University/College at Bachelor level; 4 = Completed University/College at Master level; 5 = Completed University/College at PhD level
MarStat	What is your marriage status?	0 = single; 1 = married
Income	Which best describes your monthly income in US $?	0 = < US$200; 1 = US $200-399; 2 = US $400-599; 3 = US $600-799; 4 = US $800-999; 5 = US $1000 or more
Religion	What is your religion?	0 = Christian; 1 = Muslim; 2 = Other
Nationality	What is your nationality?	0 = Kenyan; 1 = Ugandan; 2 = Tanzanian; 3 = Ethiopian
Fambackg	What is your family background?	0 = farm family; 1 = non-farm family
Upbring	Where did you grow up?	0 = rural village; 1 = small town; 2 = city
AgRuralKnow	How best do you describe your knowledge of agriculture and rural life?	0 = not much; 1 = know enough; 2 = very knowledgeable
CultLean	How best do you describe yourself culturally?	0 = liberal; 1 = moderate; 2 = conservative
Occupation	Which best describes your primary occupation?	0 = other; 1 = farmer; 2 = agricultural researcher; 3 = agricultural extension personnel; 4 = policy maker; 5 =

	a civil servant employed in the private/public sector related to agriculture; 6 = a civil servant in employed in the private/public sector NOT related to agriculture; 7 = a civil servant in a non-governmental organization sector

Appendix D. Results from Farmer surveys

D.1. The degree of challenge associated with various agricultural constraints as perceived by Kenyan, Ugandan and Tanzanian farmers

D.1.1. Kenya

Table D.1.1. The degree of challenge associated with various agricultural constraints as perceived by Kenyan farmers; in % and [number] of total participants [1127].					
	Not challenging at all	**Somewhat challenging**	**Challenging**	**Very challenging**	**No answer**
Incidence of crop pest and diseases	2 [25]	0 [0]	23 [264]	74 [829]	1 [9]
Inadequate credit services (unable to afford inputs)	4 [49]	8 [88]	15 [172]	72 [812]	1 [6]
Low crop productivity and yield	3 [33]	3 [34]	24 [267]	70 [793]	-
Debt (e.g. from having to buy inputs at high price and sell output at low prices)	0 [1]	11 [127]	20 [226]	69 [773]	-
Poor quality of produce	3 [38]	10 [118]	21 [240]	65 [731]	-
Lack of irrigation systems	6 [72]	4 [42]	26 [290]	64 [723]	-
Post-harvest losses	1 [13]	5 [51]	28 [320]	63 [710]	3 [33]
Climate change (drought, floods)	3 [35]	20 [226]	12 [135]	63 [707]	2 [24]
Inadequate extension services	9 [102]	6 [65]	21 [241]	61 [682]	3 [37]
Land degradation	1 [11]	13 [142]	29 [328]	56 [631]	1 [15]
Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	3 [37]	8 [89]	36 [406]	53 [595]	-
Spending too much time in the field (i.e. insufficient time for other activities)	4 [40]	14 [159]	30 [335]	53 [593]	-
Poor infrastructure for market access (roads, communication)	9 [97]	12 [134]	27 [306]	51 [577]	1 [13]
Lack of secure land tenure and property rights	21 [234]	19 [219]	27 [306]	30 [337]	3 [31]
Note: Figures may not add to 100% due to rounding.					

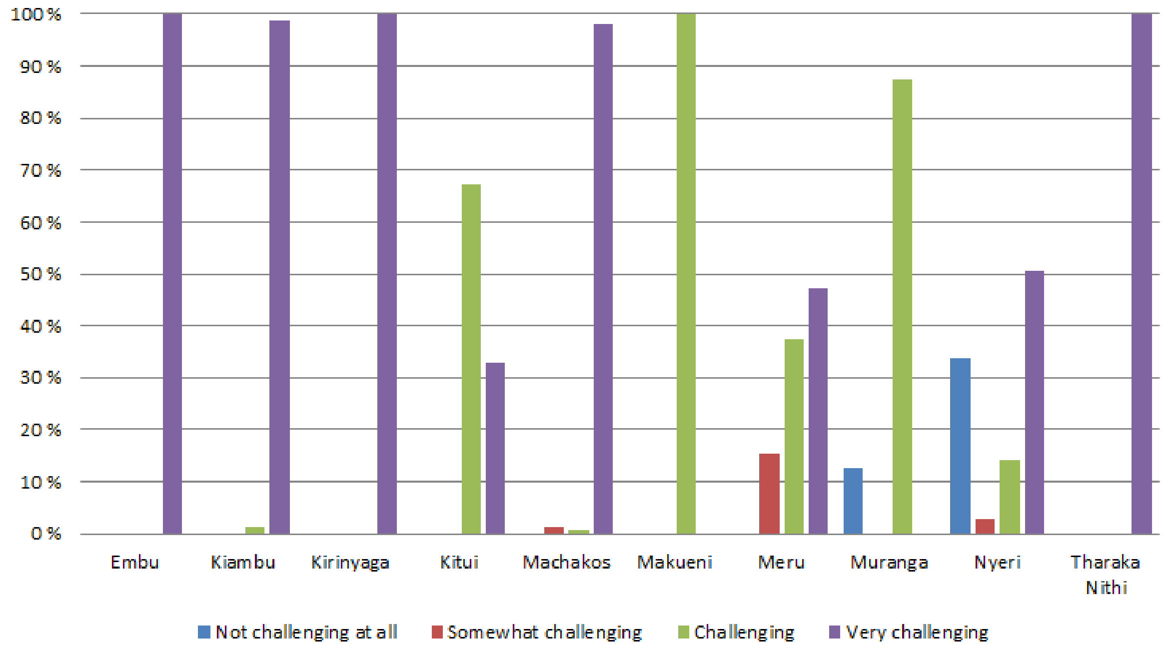


Figure D.1.1.1. The degree of challenge associated with low crop productivity and yield as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.001). Response rate: 100% (1127 out of 1127 participants).

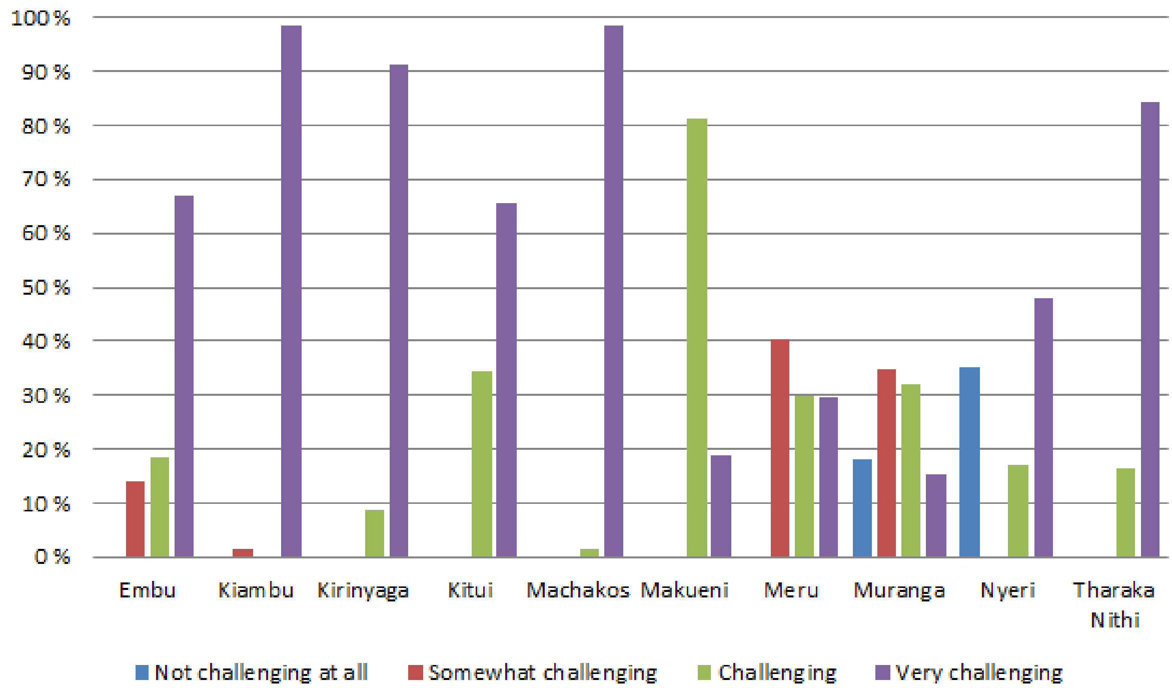


Figure D.1.1.2. The degree of challenge associated with poor quality of produce as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.001). Response rate: 100% (1127 out of 1127 participants).

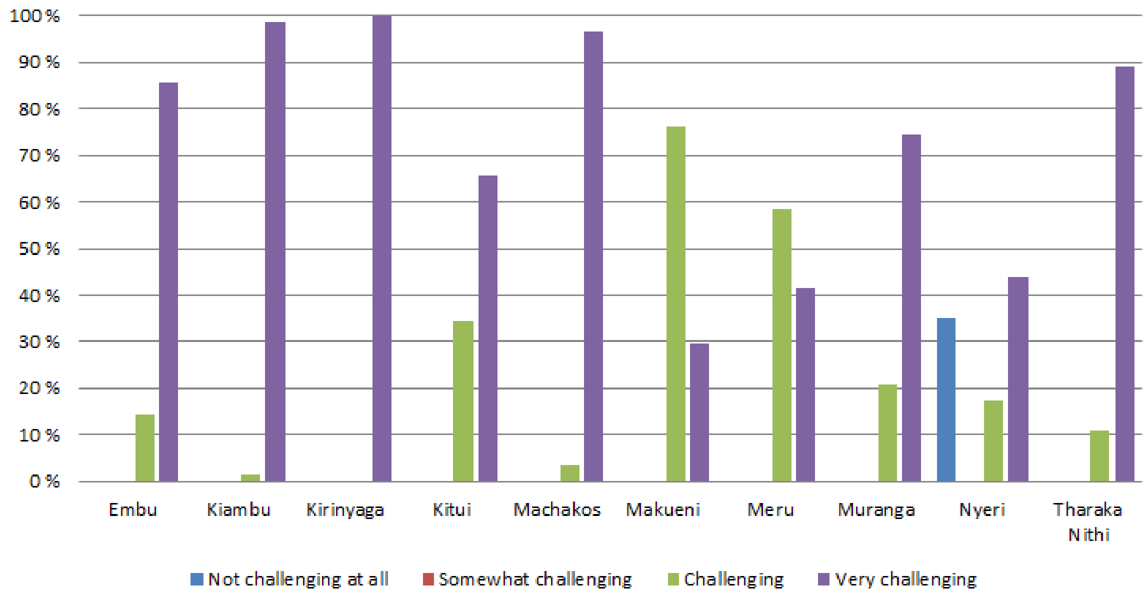


Figure D.1.1.3. The degree of challenge associated with incidence of crop pest and diseases as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.001). Response rate: ~99% (1118 out of 1127 participants).

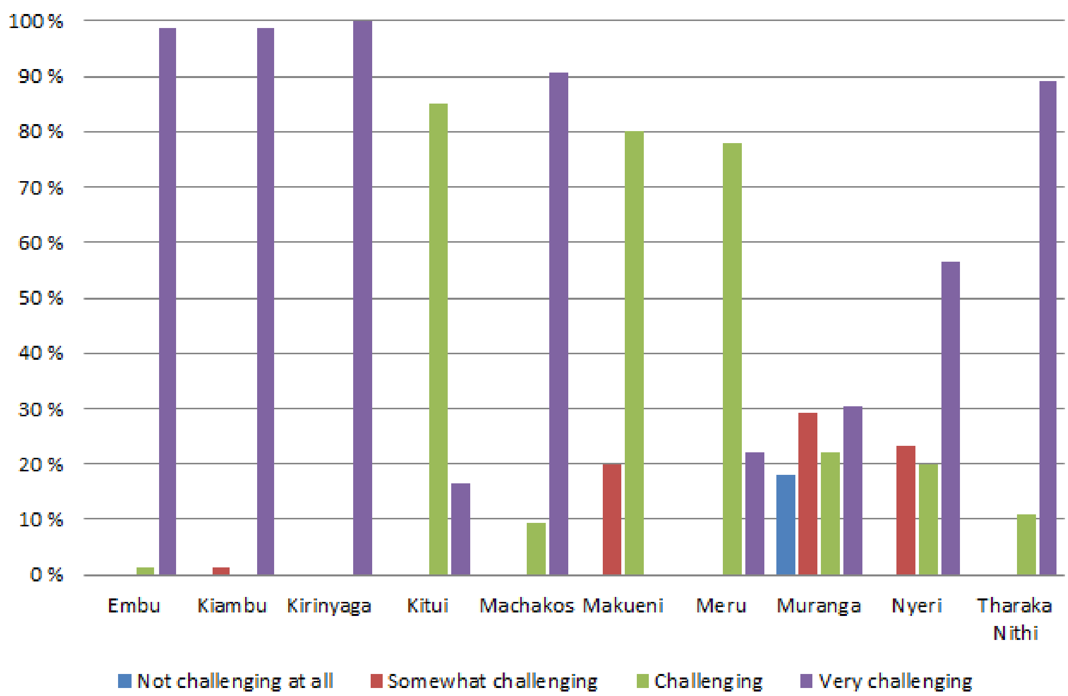


Figure D.1.1.4. The degree of challenge associated with post-harvest losses as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.001). Response rate: ~97% (1094 out of 1127 participants).

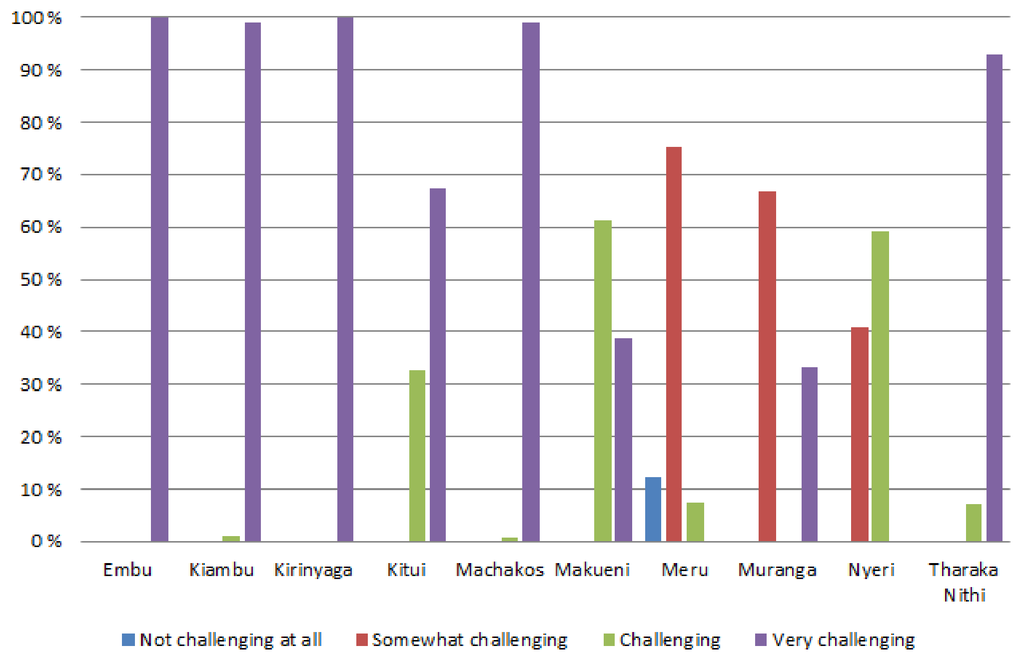


Figure D.1.1.5. The degree of challenge associated with climate change (drought, floods) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~98% (1103 out of 1127 participants).

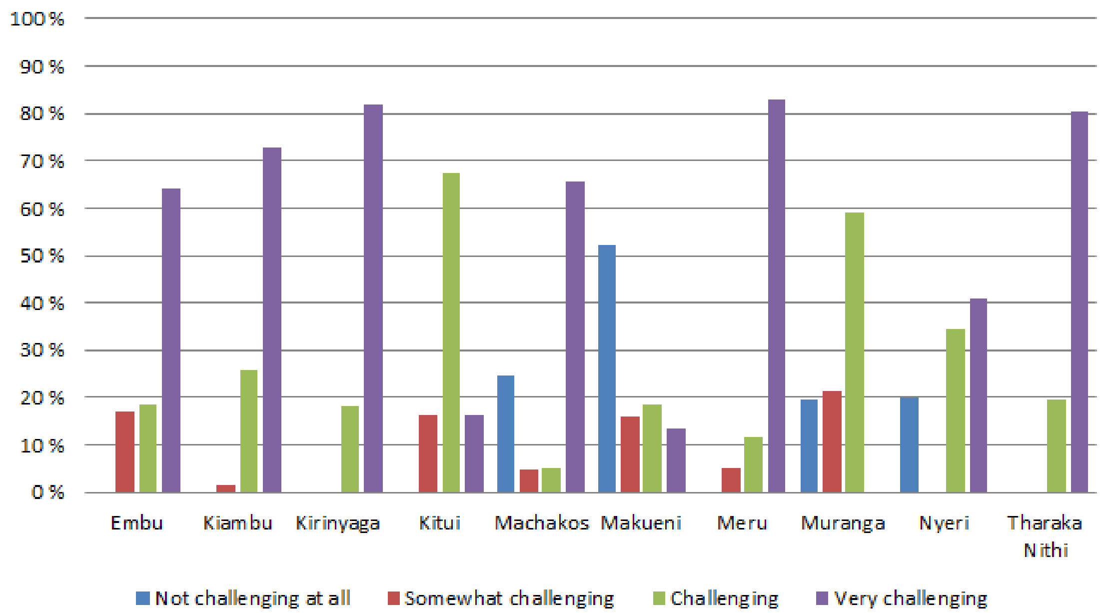


Figure D.1.1.6. The degree of challenge associated with inadequate extension services as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~97% (1090 out of 1127 participants).

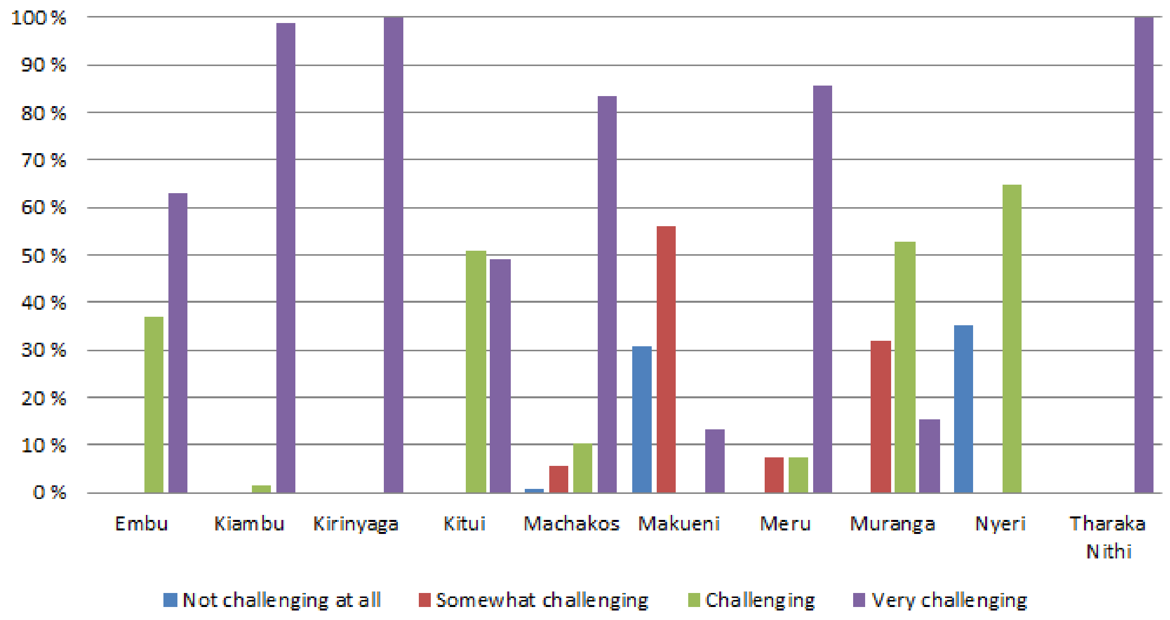


Figure D.1.1.7. The degree of challenge associated with inadequate credit services (unable to afford inputs) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~99% (1121 out of 1127 participants).

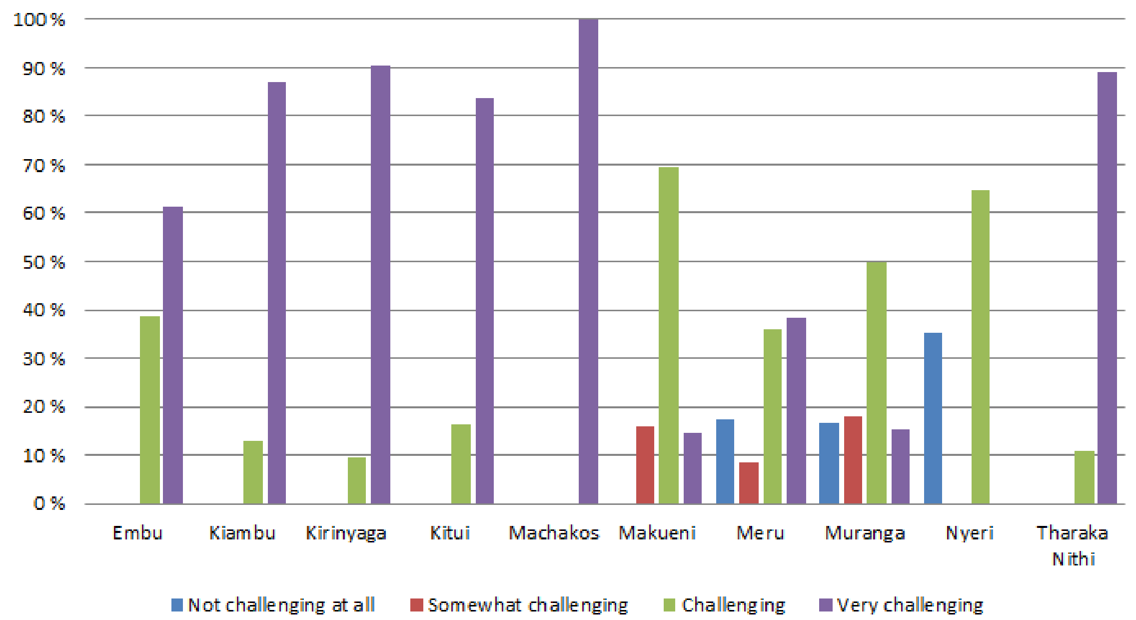


Figure D.1.1.8. The degree of challenge associated with lack of irrigation systems (unable to afford inputs) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: 100% (1127 out of 1127 participants).

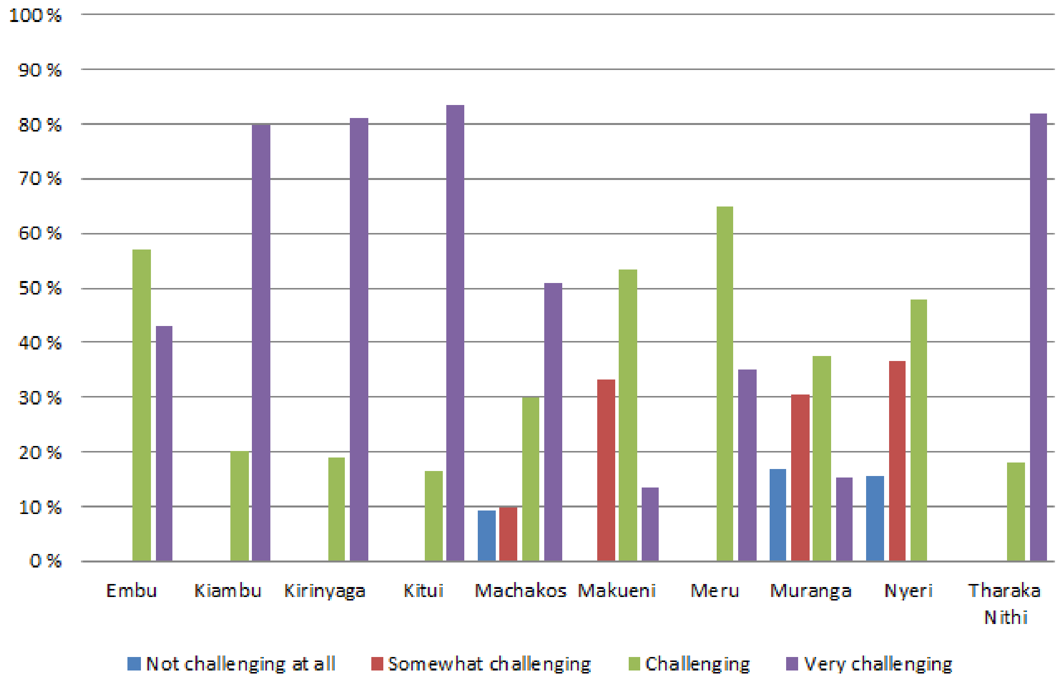


Figure D.1.1.9. The degree of challenge associated with lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~100% (1126 out of 1127 participants).

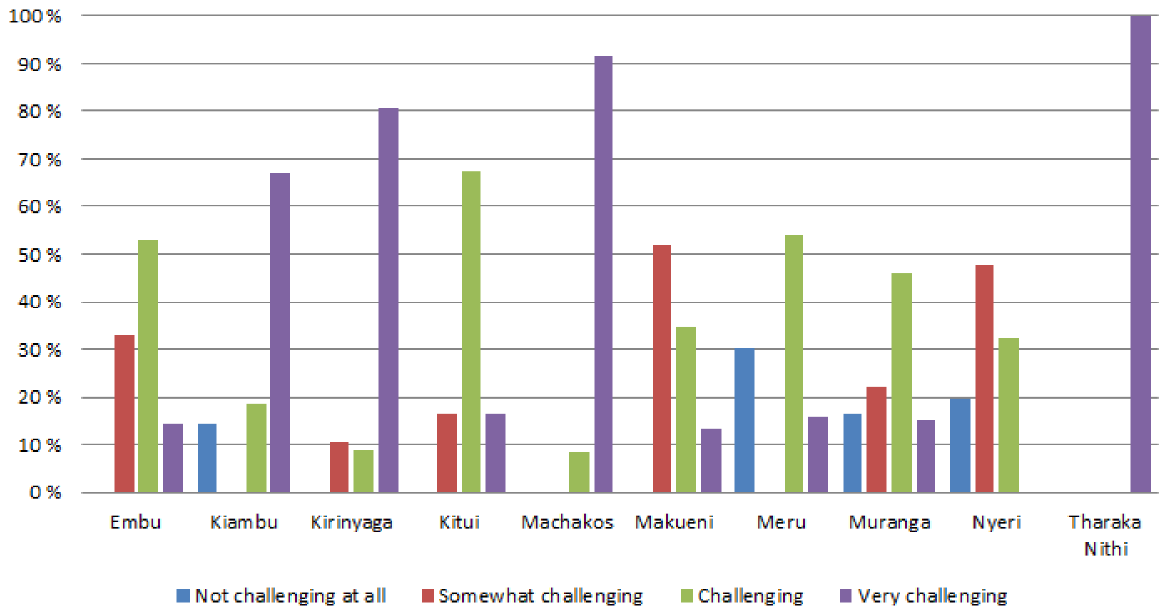


Figure D.1.1.10. The degree of challenge associated with poor infrastructure for market access (roads, communication) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~99% (1114 out of 1127 participants).

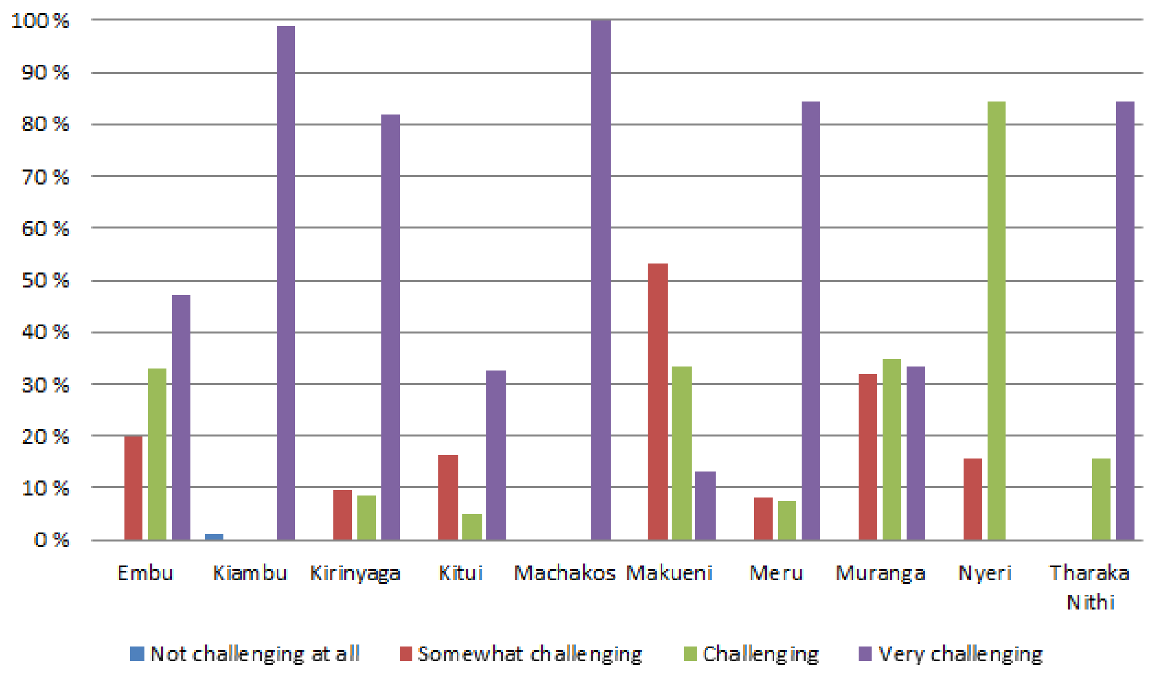


Figure D.1.1.11. The degree of challenge associated with debt (e.g. from having to buy inputs at high price and sell output at low prices) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: 100% (1127 out of 1127 participants).

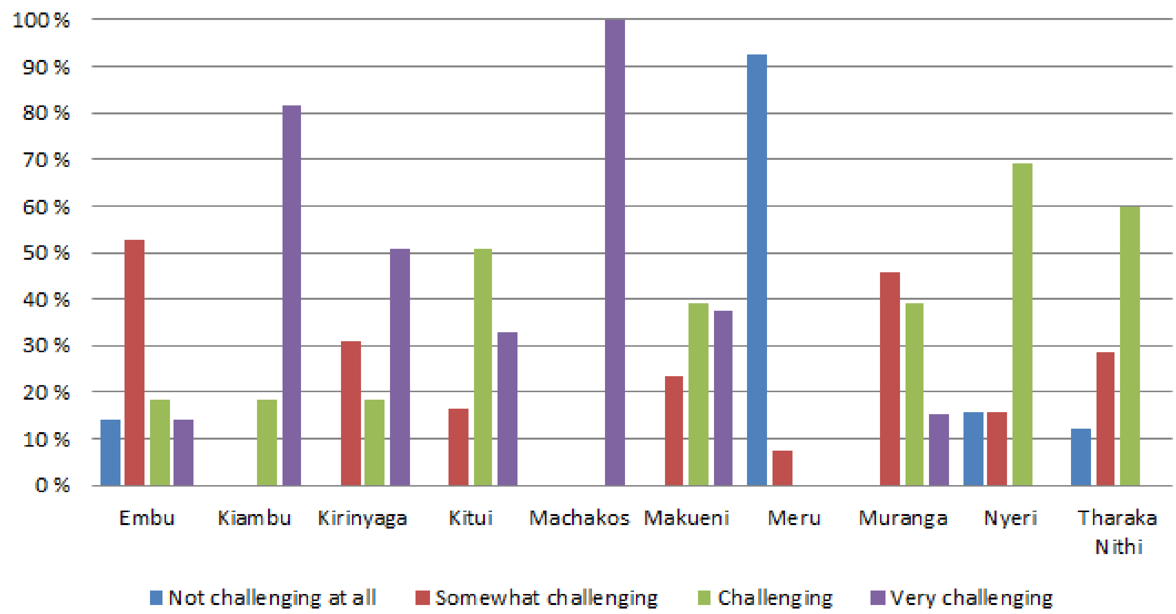


Figure D.1.1.12. The degree of challenge associated with lack of secure land tenure and property rights as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant ($p<0.001$). Response rate: ~97% (1096 out of 1127 participants).

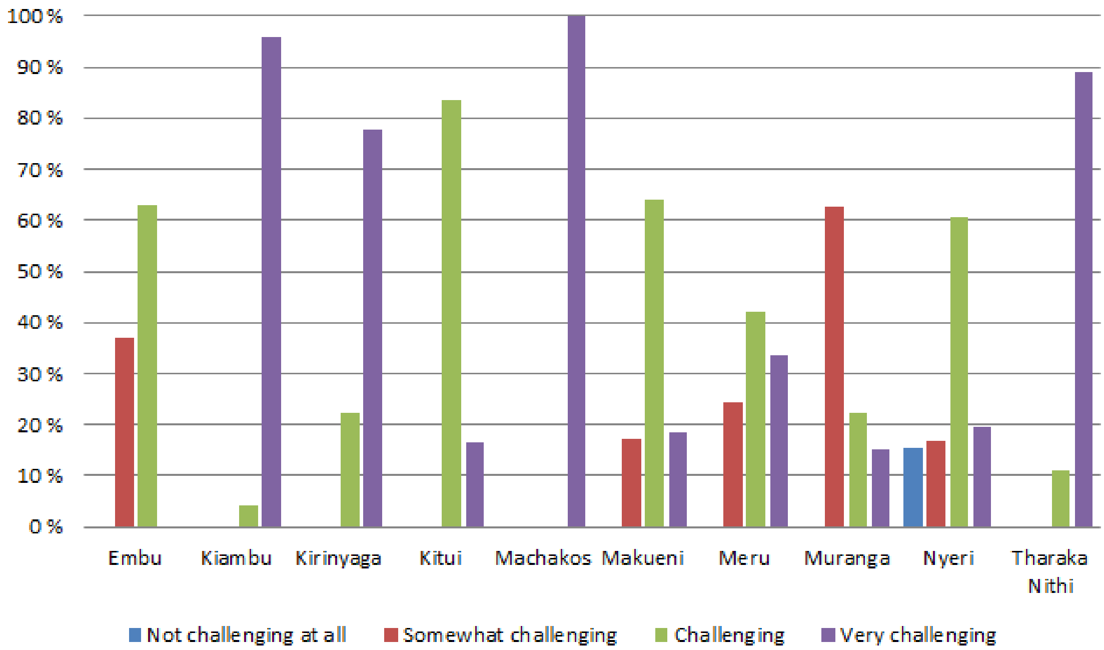


Figure D.1.1.13. The degree of challenge associated with land degradation as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.01). Response rate: ~99% (1112 out of 1127 participants).

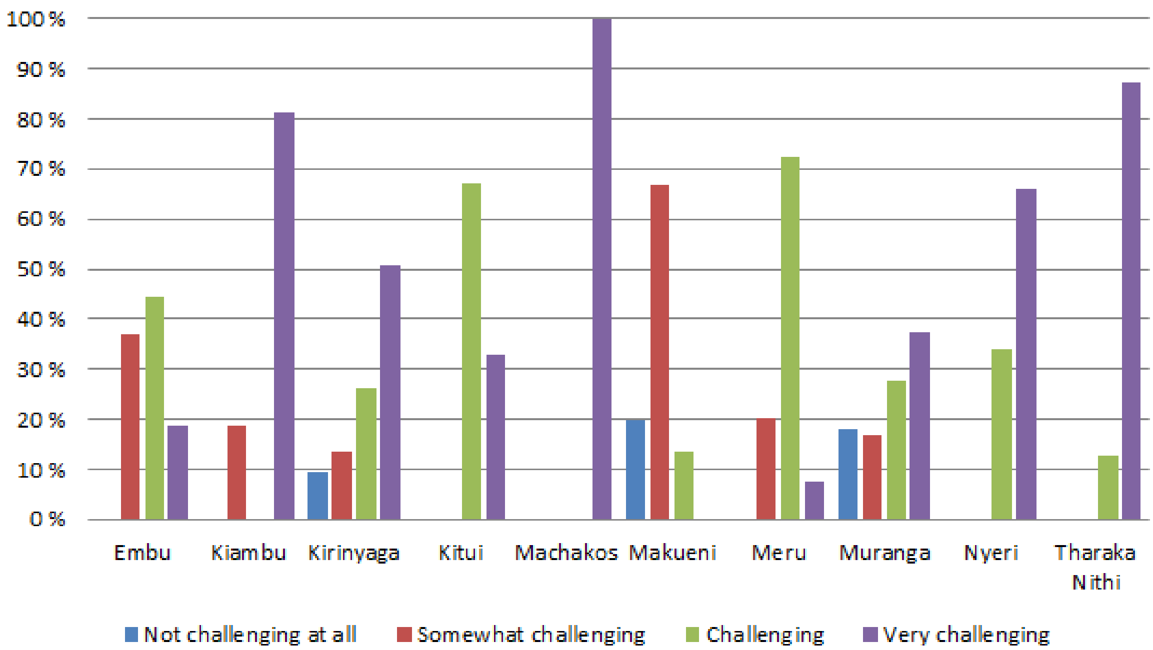


Figure D.1.1.14. The degree of challenge associated with spending too much time in the field (i.e. insufficient time for other activities) as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the degree of challenge was significant (p<0.01). Response rate: 100% (1127 out of 1127 participants).

D.1.2. Uganda

Please note that data at the group-level is not presented, as groups expressed a high degree of coherence in the perceived degree of challenge for most constriants.

Table D.1.2. The degree of challenge associated with various agricultural constraints as perceived by Ugandan farmers; in ~% and [number] of total participants [142].

	Not challenging at all	Somewhat challenging	Challenging	Very challenging	No answer
Climate change (drought, floods)	0 [0]	0 [0]	0 [0]	93 [132]	7 [10]
Lack of irrigation systems	0 [0]	0 [0]	0 [0]	93 [132]	7 [10]
Land degradation	0 [0]	0 [0]	0 [0]	93 [132]	7 [10]
Incidence of crop pest and diseases	0 [0]	0 [0]	8 [12]	85 [120]	7 [10]
Debt (e.g. from having to buy inputs at high price and sell output at low prices)	0 [0]	0 [0]	8 [11]	85 [121]	7 [10]
Lack of secure land tenure and property rights	0 [0]	0 [0]	11 [16]	82 [116]	7 [10]
Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	11 [16]	0 [0]	0 [0]	82 [116]	7 [10]
Inadequate extension services	0 [0]	0 [0]	13 [18]	80 [114]	7 [10]
Low crop productivity and yield	0 [0]	0 [0]	20 [29]	73 [103]	7 [10]
Poor quality of produce	0 [0]	0 [0]	22 [31]	71 [101]	7 [10]
Inadequate credit services (unable to afford inputs)	0 [0]	23 [32]	13 [18]	58 [82]	7 [10]
Poor infrastructure for market access (roads, communication)	8 [11]	13 [18]	16 [23]	56 [80]	7 [10]
Post-harvest losses	0 [0]	26 [37]	16 [23]	51 [72]	7 [10]
Spending too much time in the field (i.e. insufficient time for other activities)	0 [0]	17 [24]	21 [30]	44 [62]	18 [26]
Note: Figures may not add to 100% due to rounding.					

D.1.3. Tanzania

Table D.1.3. The degree of challenge associated with various agricultural constraints as perceived by Tanzanian farmers; in % and [number] of total participants [805].					
Constraints	**Not challenging at all**	**Somewhat challenging**	**Challenging**	**Very challenging**	**No answer**
Climate change (drought, floods)	0 [2]	3 [28]	26 [211]	68 [551]	2 [13]
Lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.)	3 [27]	29 [234]	10 [79]	58 [464]	0 [1]
Lack of irrigation systems	0 [3]	7 [60]	41 [327]	51 [408]	1 [7]
Low crop productivity and yield	0 [3]	12 [100]	45 [366]	42 [336]	-
Incidence of crop pest and diseases	1 [8]	18 [146]	40 [324]	40 [325]	0 [2]
Land degradation	13 [103]	18 [146]	40 [321]	28 [223]	1 [12]
Poor infrastructure for market access (roads, communication)	0 [3]	37 [294]	38 [302]	25 [202]	0 [4]
Inadequate extension services	26 [206]	30 [240]	20 [165]	23 [182]	1 [12]
Poor quality of produce	2 [16]	33 [269]	44 [355]	20 [164]	0 [1]
Post-harvest losses	3 [25]	27 [215]	56 [448]	14 [115]	0 [2]
Inadequate credit services (unable to afford inputs)	10 [82]	31 [247]	46 [374]	12 [98]	0 [4]
Debt (e.g. from having to buy inputs at high price and sell output at low prices)*	4 [34]	32 [254]	55 [440]	10 [77]	-
Lack of secure land tenure and property rights	60 [480]	26 [211]	9 [72]	5 [37]	1 [5]
Spending too much time in the field (i.e. insufficient time for other activities)	9 [75]	45 [366]	40 [323]	5 [39]	0 [2]
Note: Figures may not add to 100% due to rounding.					

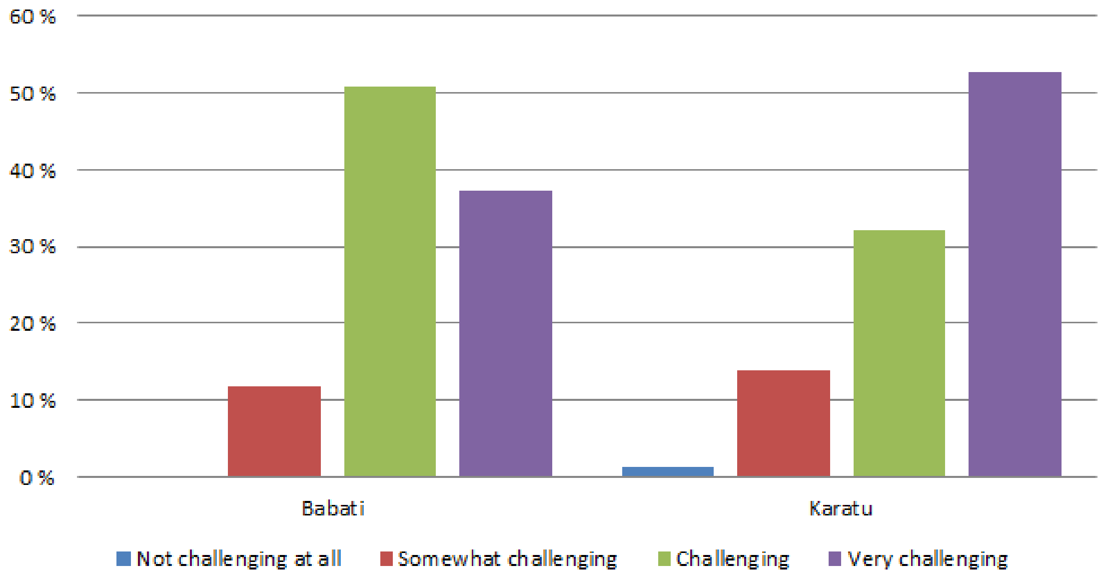


Figure D.1.3.1. The degree of challenge associated with low crop productivity and yield as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.001). Response rate: 100% (805 out of 805 participants).

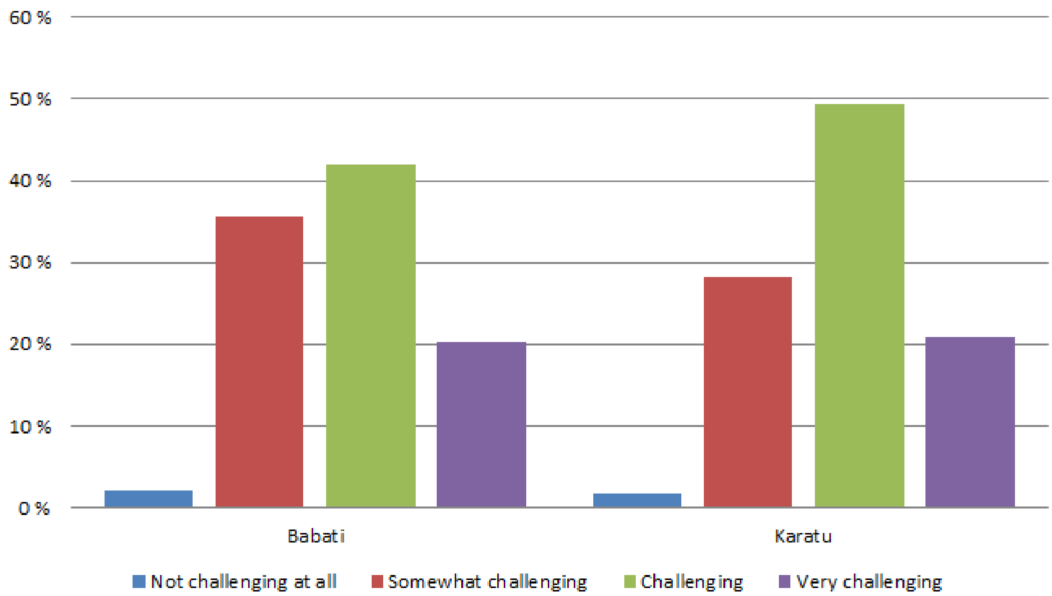


Figure D.1.3.2. The degree of challenge associated with poor quality of produce as perceived byTanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was NS (p>0.05). Response rate: ~100% (804 out of 805 participants).

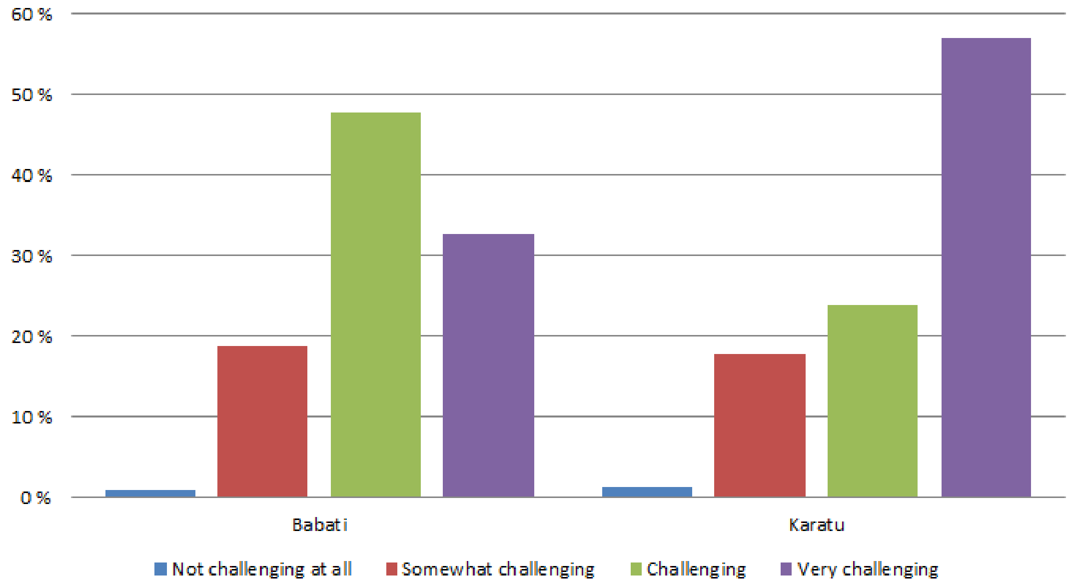


Figure D.1.3.3. The degree of challenge associated with incidence of crop pest and diseases as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~98% (793 out of 805 participants).

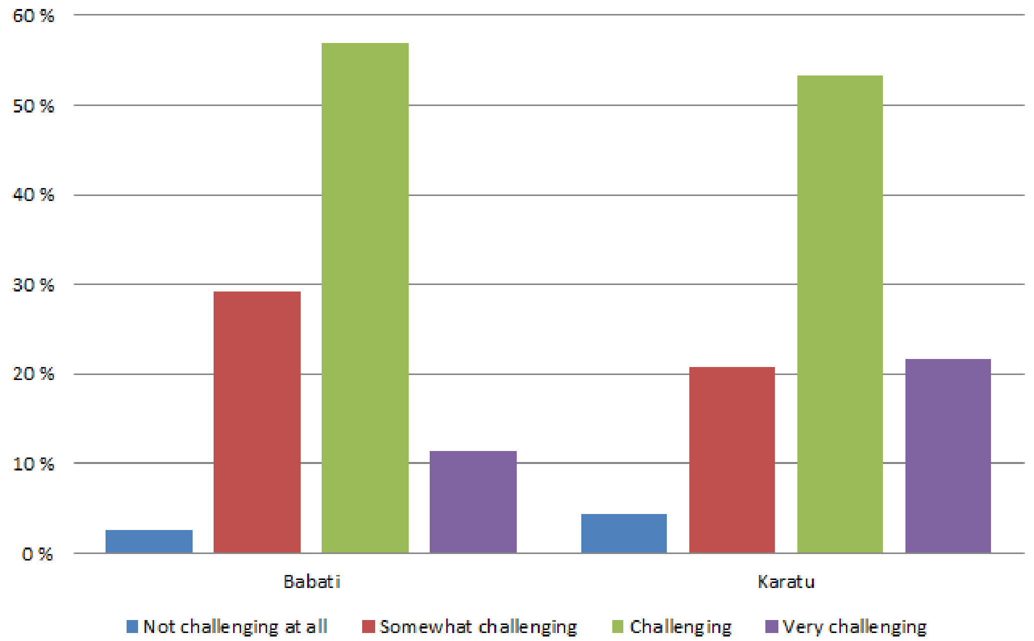


Figure D.1.3.4. The degree of challenge associated with post-harvest losses as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~100 (803 out of 805 participants).

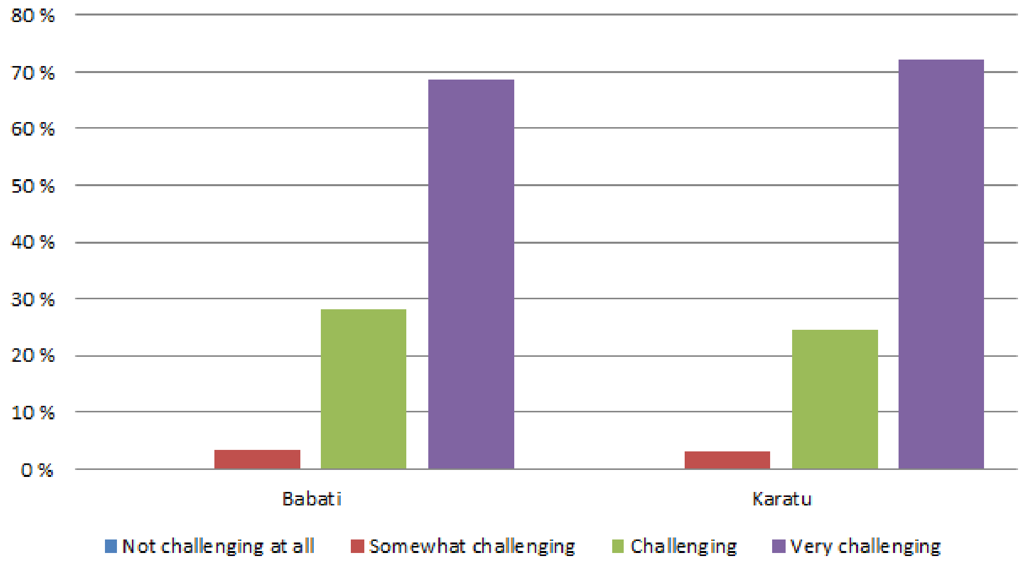


Figure D.1.3.5. The degree of challenge associated with climate change (drought, floods) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was NS (p>0.05). Response rate: ~98% (792 out of 805 participants).

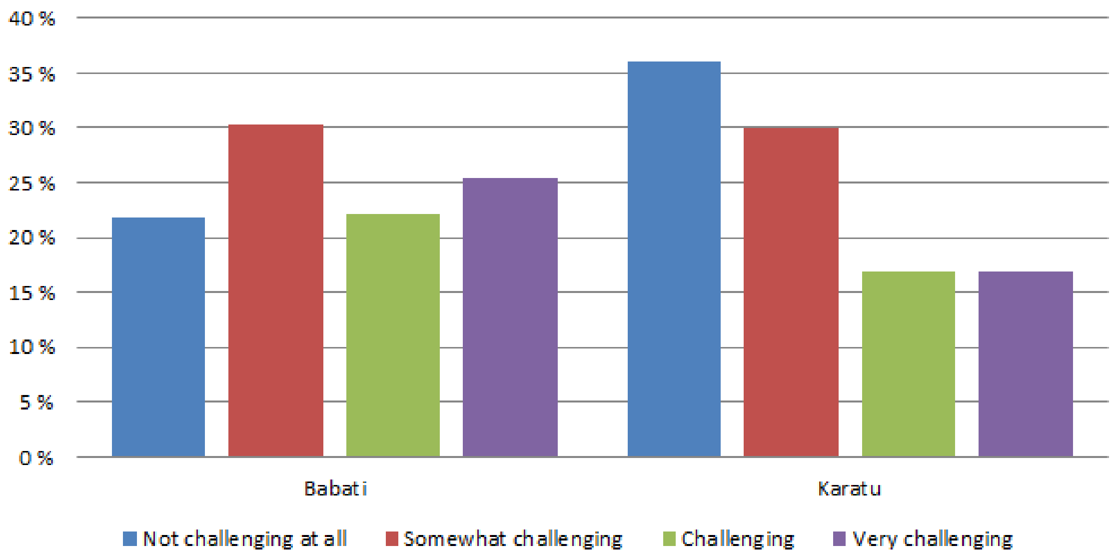


Figure D.1.3.6. The degree of challenge associated with inadequate extension services as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.001). Response rate: ~98% (793 out of 805 participants).

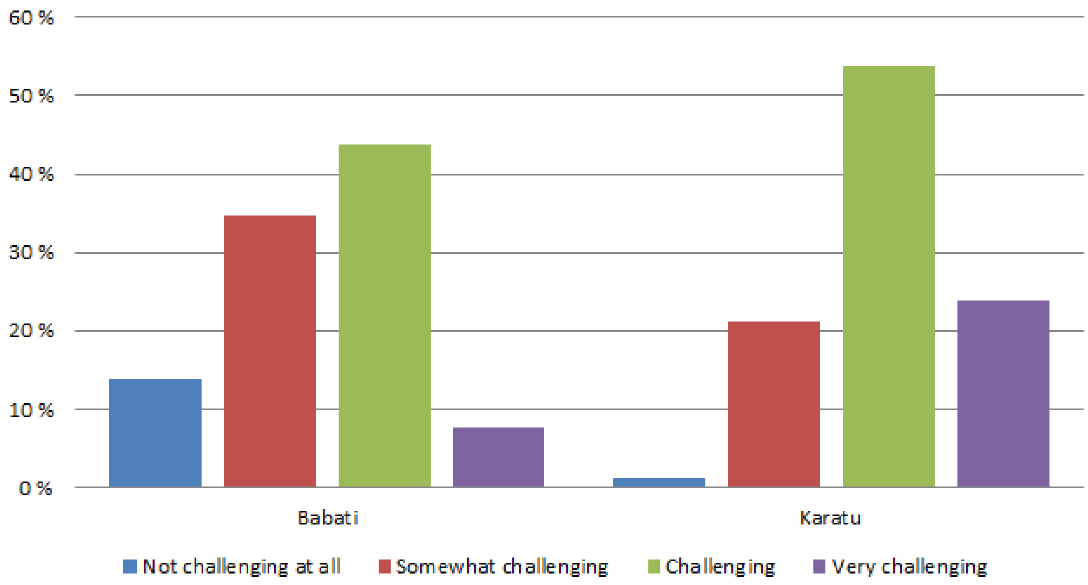


Figure D.1.3.7. The degree of challenge associated with inadequate credit services (unable to afford inputs) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~99% (801 out of 805 participants).

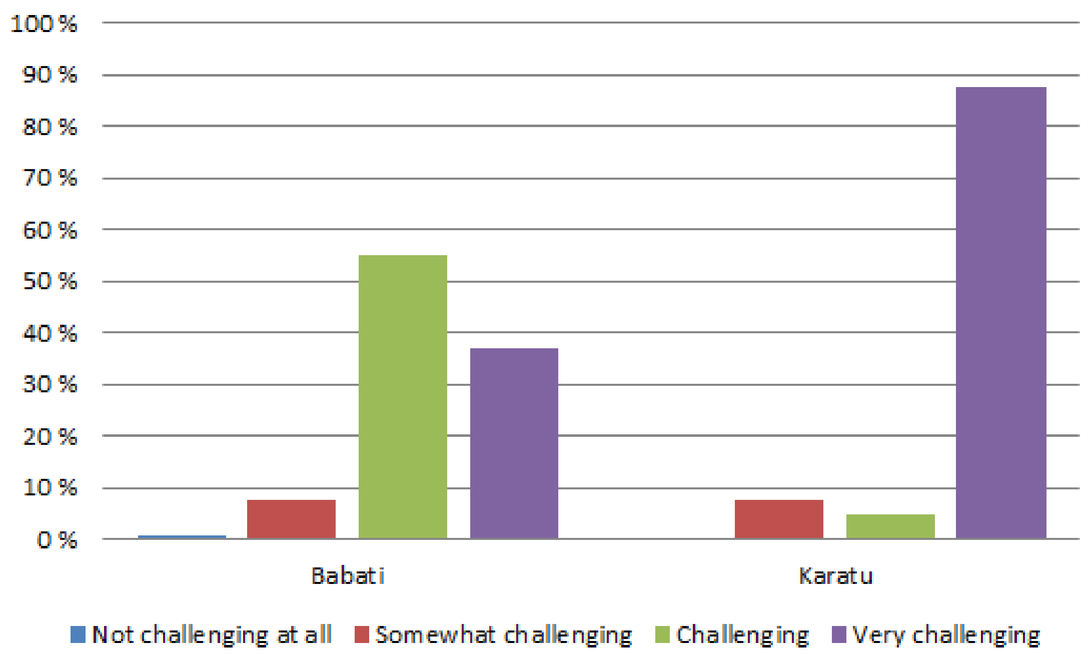


Figure D.1.3.8. The degree of challenge associated with lack of irrigation systems (unable to afford inputs) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~99% (798 out of 805 participants).

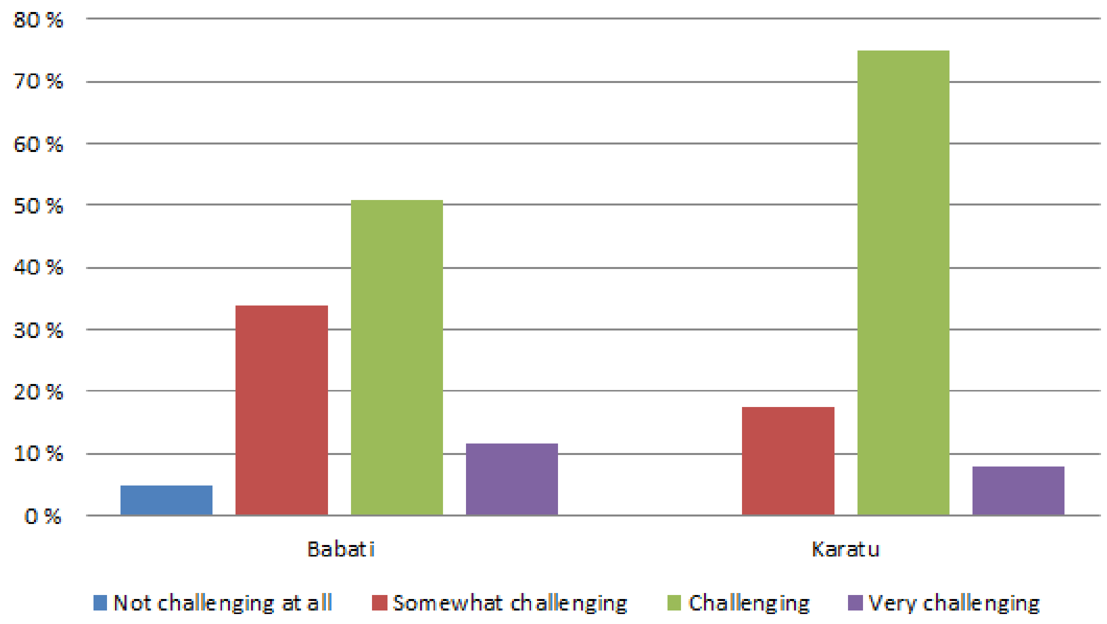


Figure D.1.3.9. The degree of challenge associated with lack of improved technologies (varieties, soil fertility, pest and disease management practices, mechanical tools, processing devices, storage, etc.) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.001). Response rate: ~100% (804 out of 805 participants).

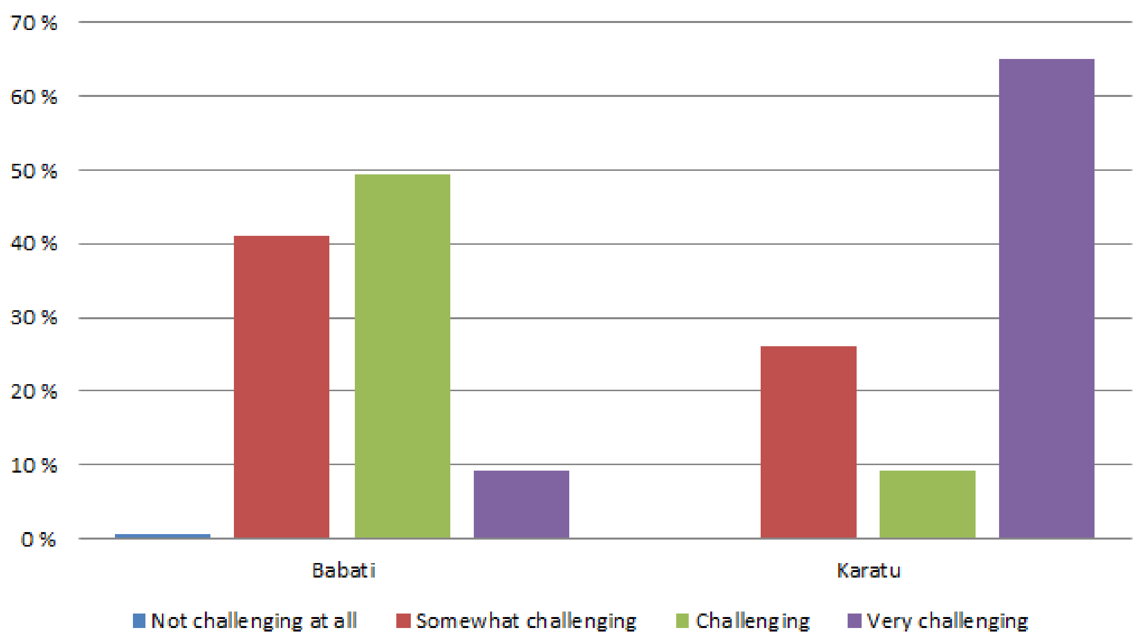


Figure D.1.3.10. The degree of challenge associated with poor infrastructure for market access (roads, communication) as perceived Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.001). Response rate: ~99% (801 out of 805 participants).

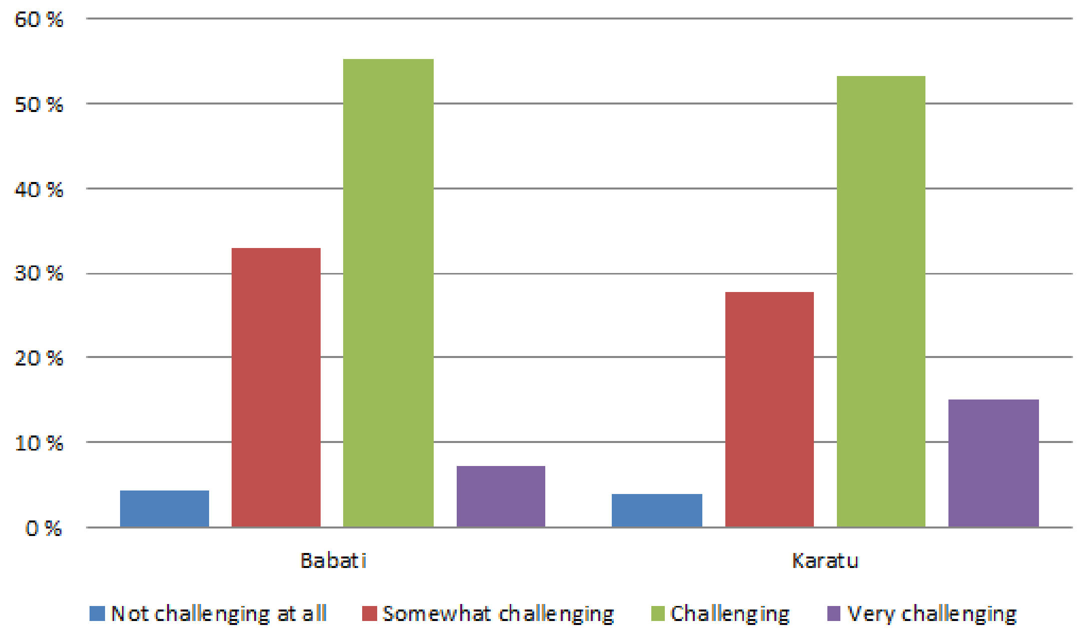


Figure D.1.3.11. The degree of challenge associated with debt (e.g. from having to buy inputs at high price and sell output at low prices) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.01). Response rate: 100% (805 out of 805 participants).

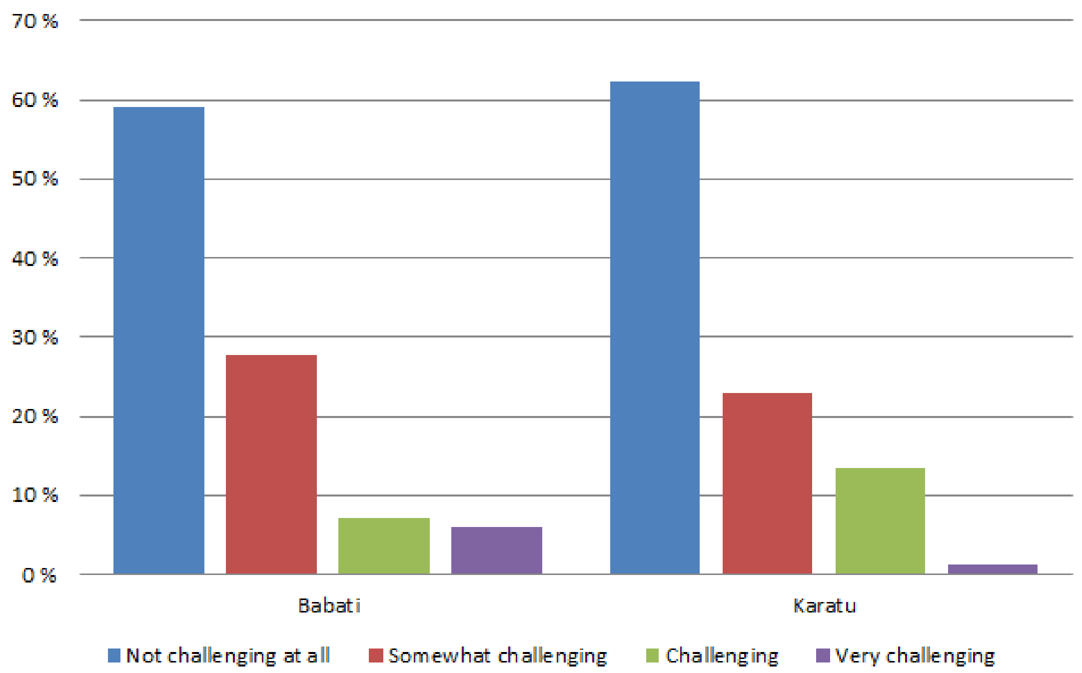


Figure D.1.3.12. The degree of challenge associated with lack of secure land tenure and property rights as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant (p<0.001). Response rate: ~99% (800 out of 805 participants).

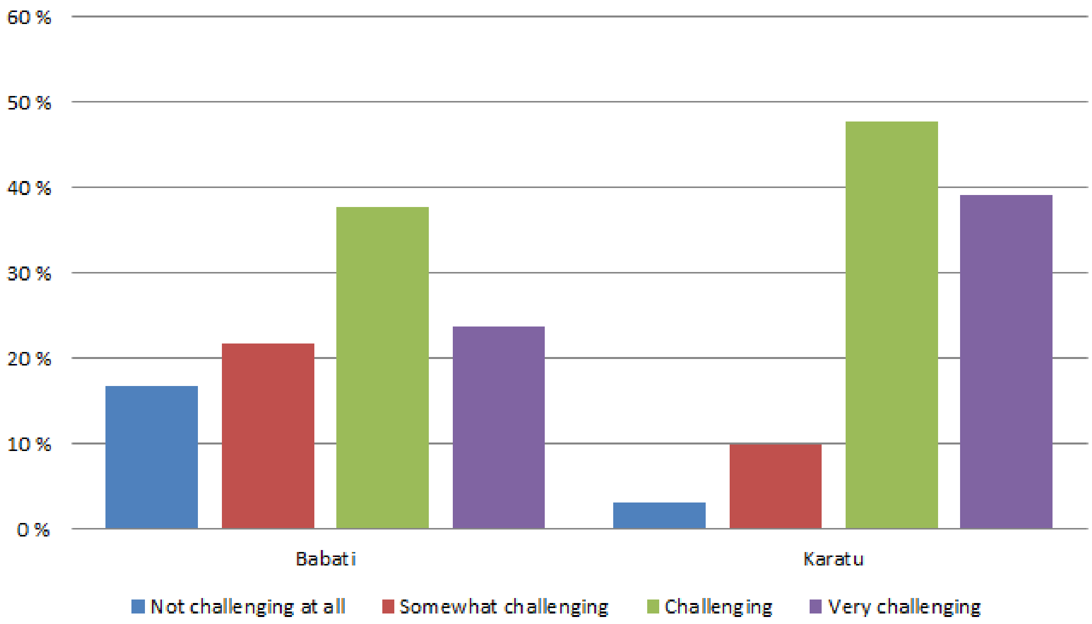


Figure D.1.3.13. The degree of challenge associated with land degradation as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~98% (793 out of 805 participants).

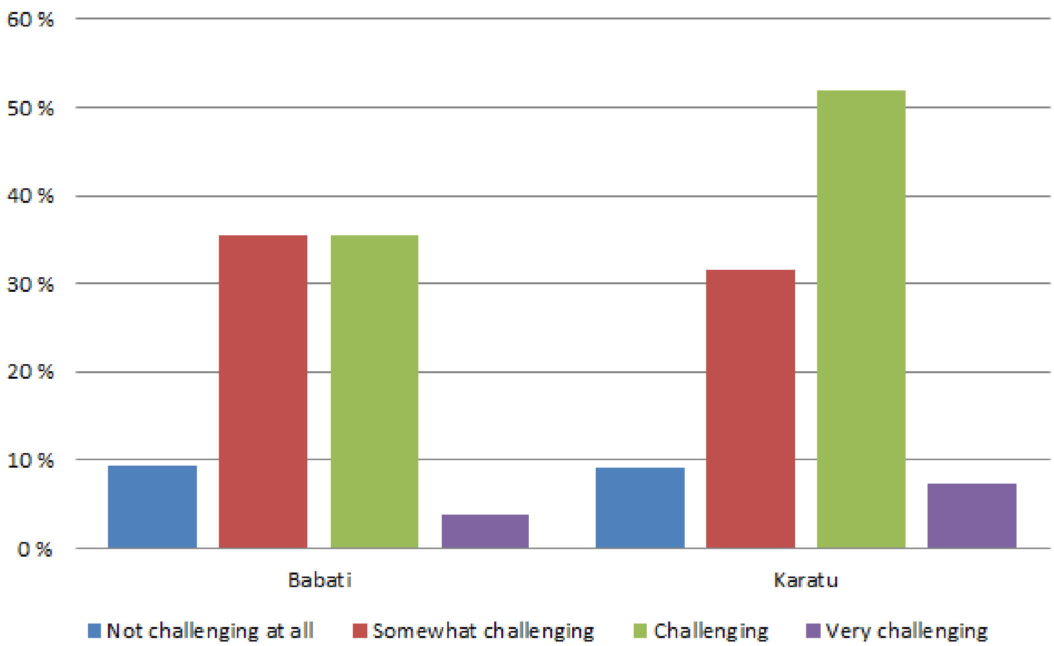


Figure D.1.3.14. The degree of challenge associated with spending too much time in the field (i.e. insufficient time for other activities) as perceived by Tanzania farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the degree of challenge was significant ($p<0.001$). Response rate: ~100% (803 out of 805 participants).

D.2. Level of influence of religious beliefs on acceptance of genetically modified (GM) crops as perceived by Kenyan, Ugandan and Tanzanian farmers

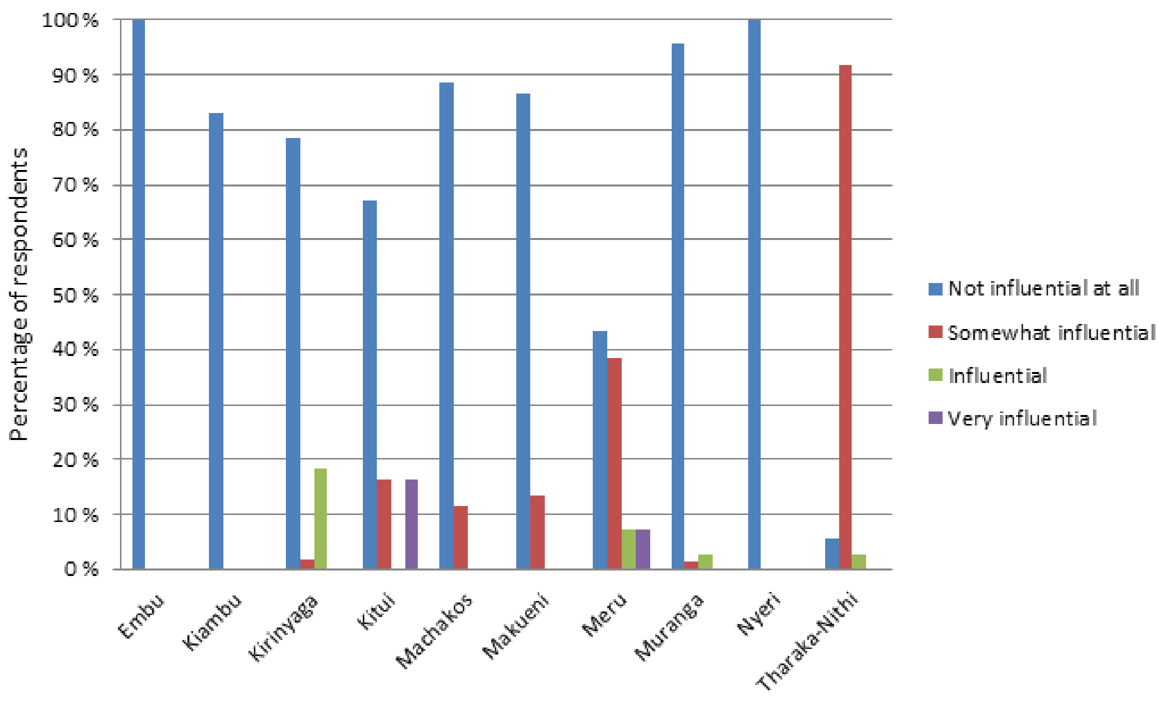


Figure D.2.1. Level of Influence of religious beliefs on acceptance of genetically modified (GM) crops among Kenyan farmers across ten counties (in % of respondents). Across all counties, an average of ~64% of farmers found religious beliefs "not influential at all", ~30% "somewhat influential", ~4% "influential" and ~2% "very influential" on their acceptance of GM crops. The association between geographical location (county) and the level of religious influence on acceptance of GM crops was significant (p<0.001). Response rate: ~98% (1108 out of 1127 participants).

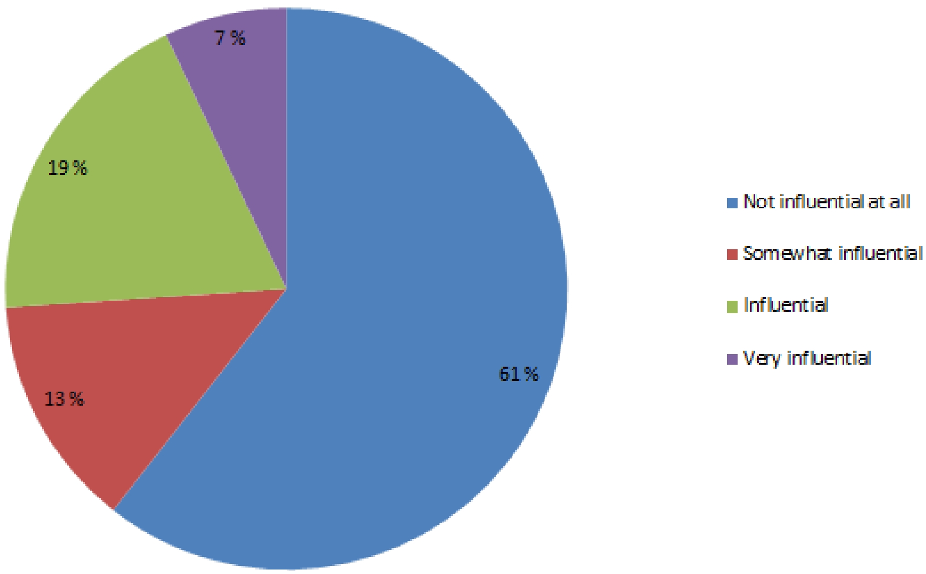


Figure D.2.2. Level of influence of religious beliefs on acceptance of genetically modified (GM) crops among Ugandan farmers in the districts Wakiso, Mukono, Mpiji and Lowelo (in % of respondents). Response rate: 100 % (142 out of 142 participants).

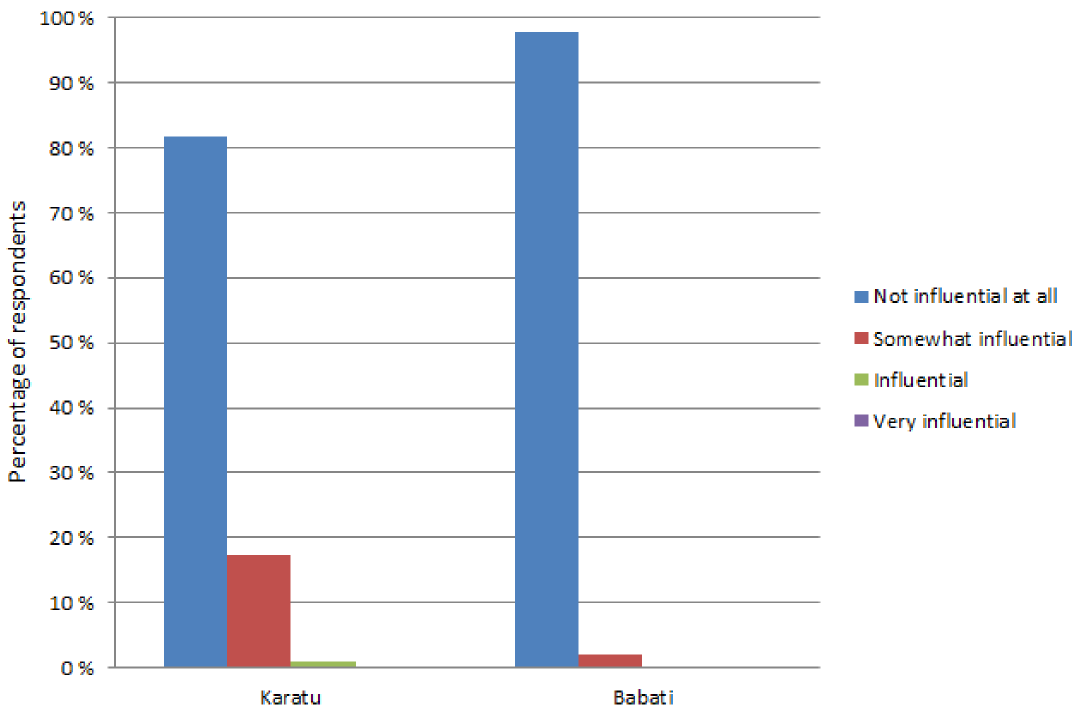


Figure D.2.3. Level of influence of religious beliefs on acceptance of genetically modified (GM) crops among Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). Across districts, an average of 90% of Tanzanian farmers found religious beliefs "not influential at all", 9.5 % "somewhat influential" and 0.5% "influential" on their acceptance of GM crops. The association between geographical location (district) and the level of religious influence on acceptance of GM crops was significant ($p<0.001$). Response rate: ~100% (804 out of 805 participants).

D.3. Level of concern associated with potential impacts of genetically modified (GM) crops as perceived by Kenyan farmers on a county-level

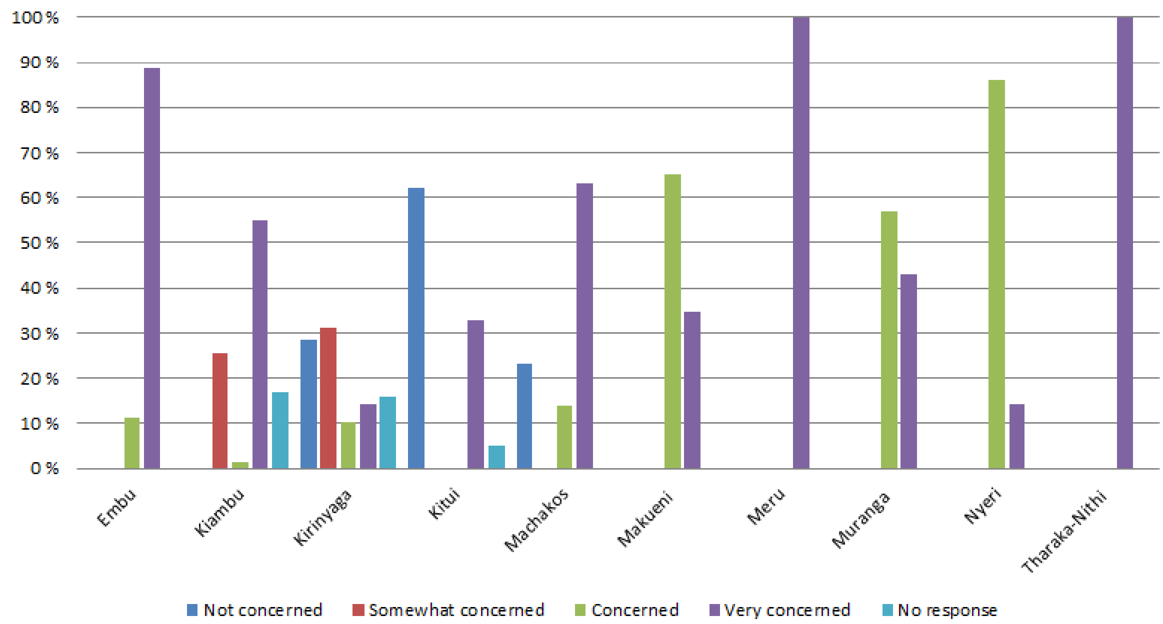


Figure D.3.1. Level of concern associated with potential negative health effects due to genetically modified (GM) crops as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~97% (1093 out of 1127 participants).

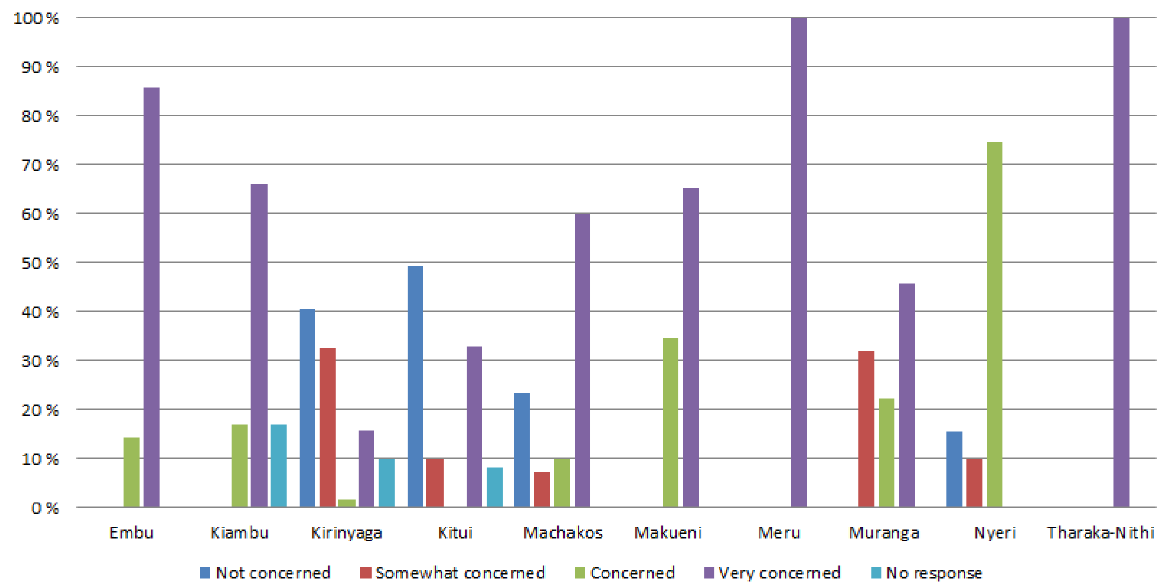


Figure D.3.2. Level of concern associated with potential negative environmental effects due to genetically modified (GM) crops as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~98% (1099 out of 1127 participants).

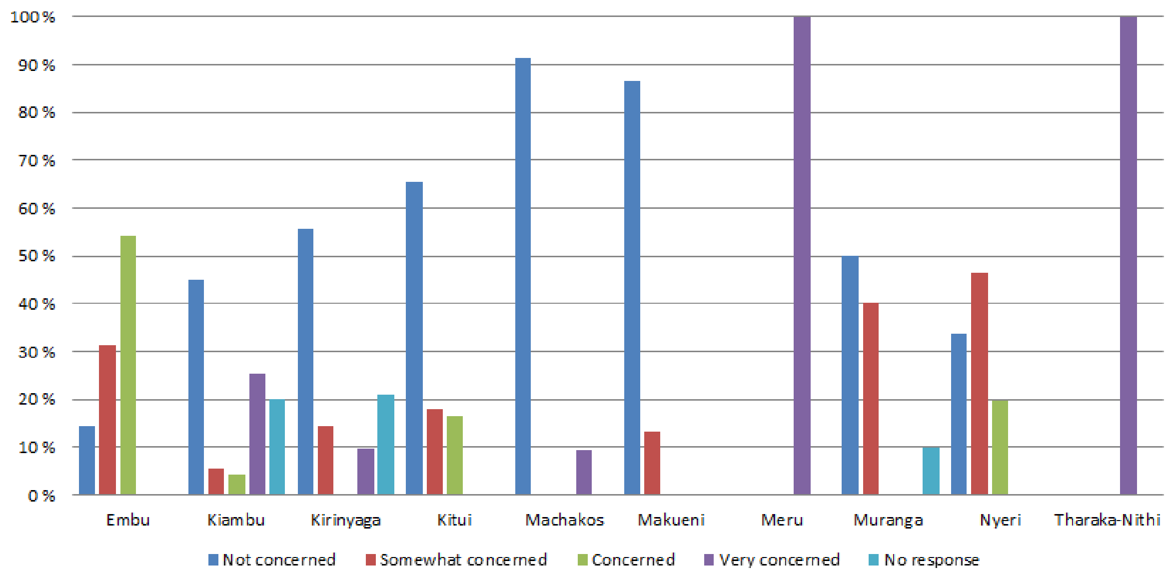


Figure D.3.3. Level of concern associated with potential religious/cultural concerns due to genetically modified (GM) crops as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~96% (1081 out of 1127 participants).

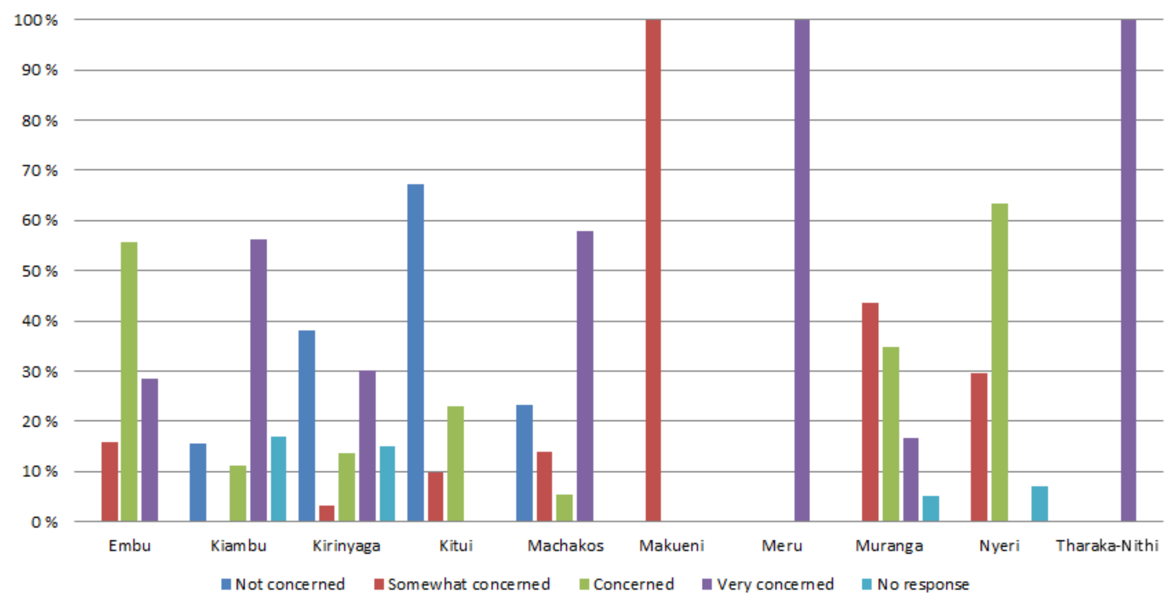


Figure D.3.4. Level of concern associated with intellectual property rights protection and loss of Farmers' Rights due to genetically modified (GM) crops as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~98% (1099 out of 1127 participants).

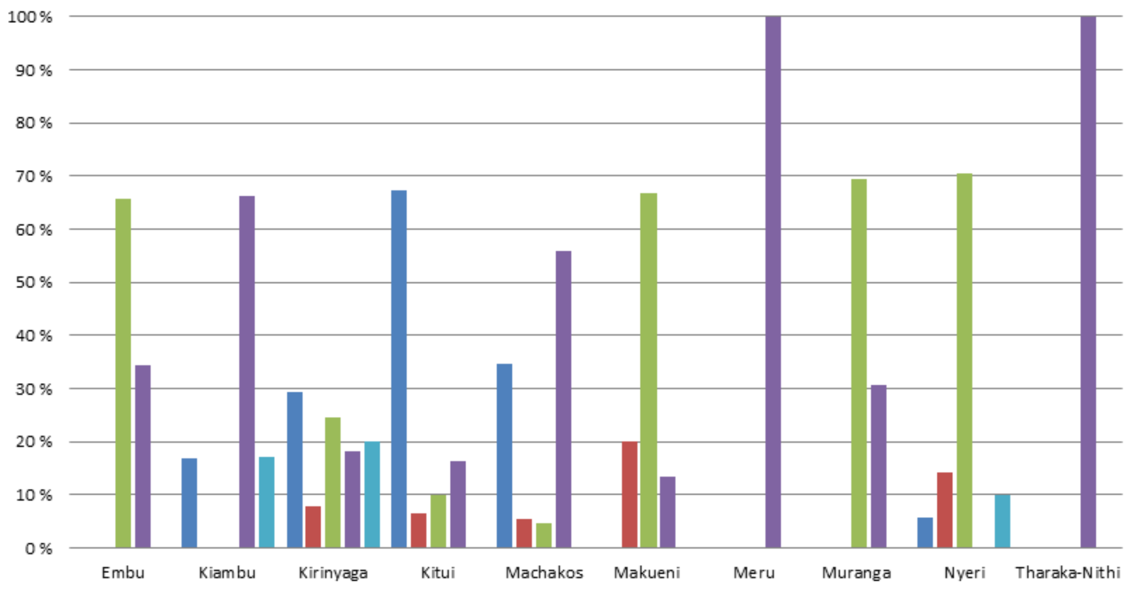


Figure D.3.5. Level of concern associated with consumer reluctance to buy genetically modified (GM) products and hence loss of income as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~96% (1084 out of 1127 participants).

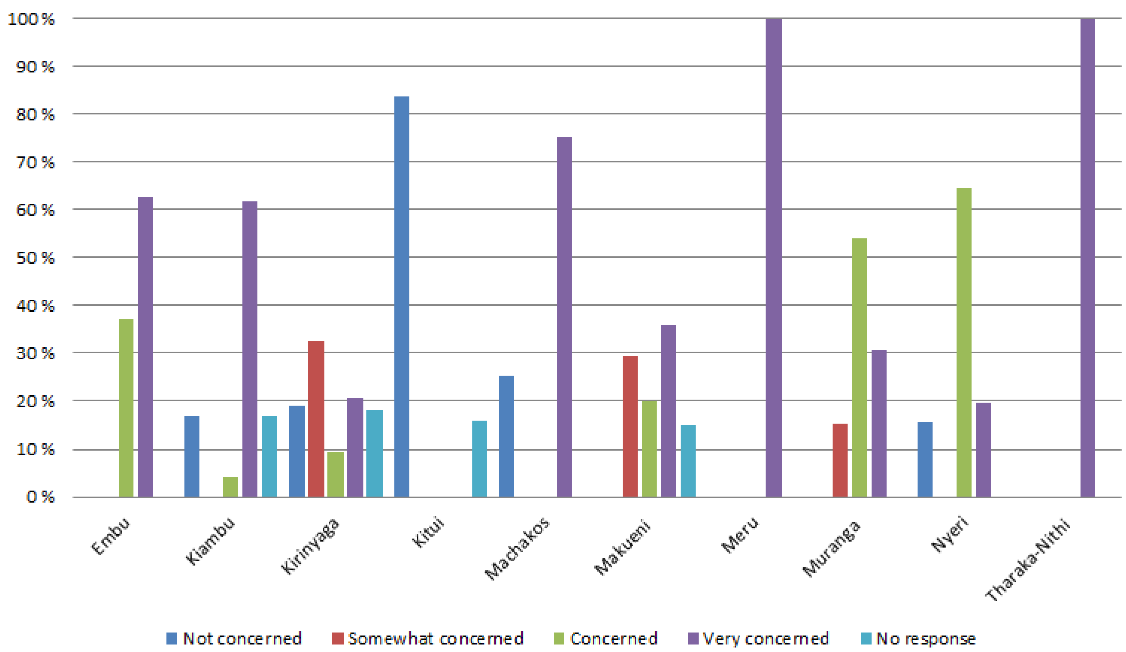


Figure D.3.6. Level of concern associated with low profitability of genetically modified (GM) crop products and hence increased debt as perceived by Kenyan farmers across ten counties (in % of respondents). The association between geographical location (county) and the level of concern was significant (p<0.001). Response rate: ~95% (1072 out of 1127 participants).

D.4. Level of concerns associated with potential impacts of genetically modified (GM) crops as perceived by Tanzanian farmers on a district-level

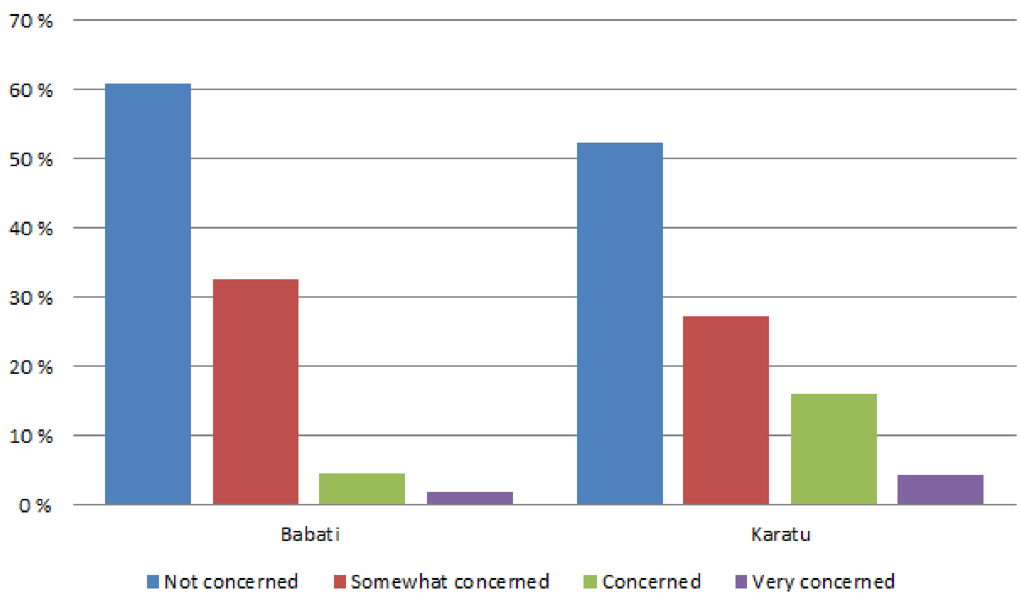


Figure D.4.1. Level of concern associated with potential negative health effects due to genetically modified (GM) crops as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p<0.001). Response rate: ~99% (798 out of 805 participants).

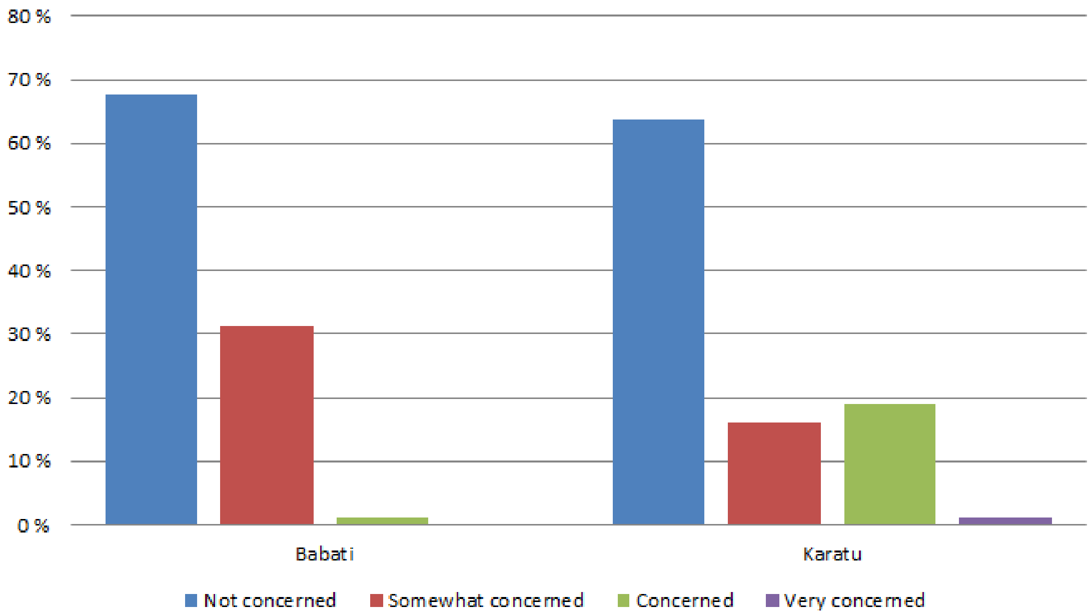


Figure D.4.2. Level of concern associated with potential negative environmental effects due to genetically modified (GM) as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p<0.001). Response rate: 100% (805 out of 805 participants).

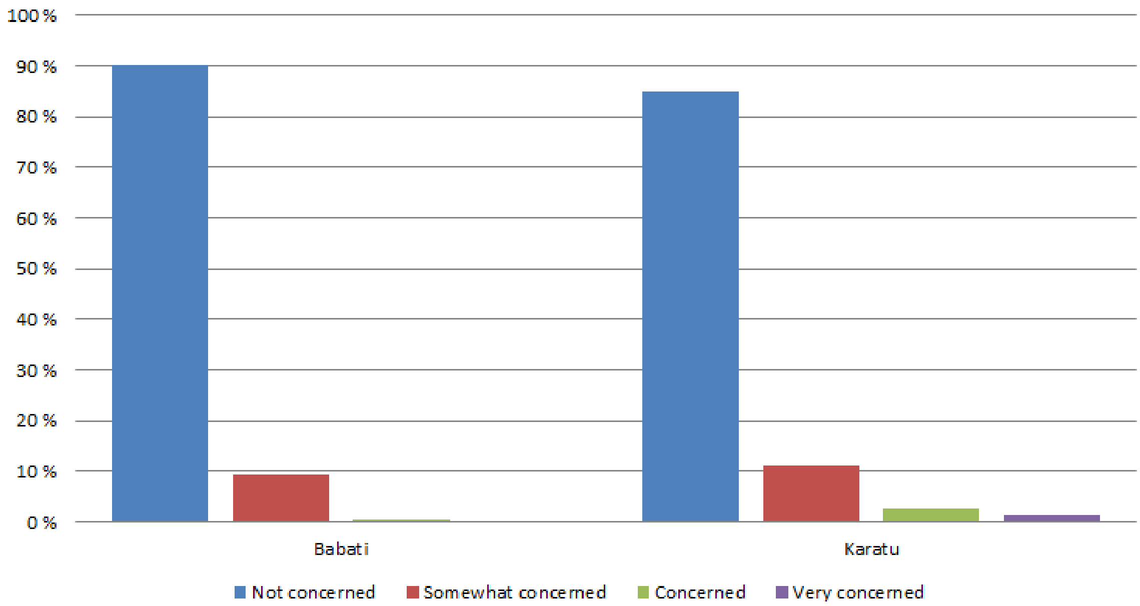


Figure D.4.3. Level of concern associated with potential religious/cultural concerns due to genetically modified (GM) crops as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p=0.001). Response rate: ~99% (798 out of 805 participants).

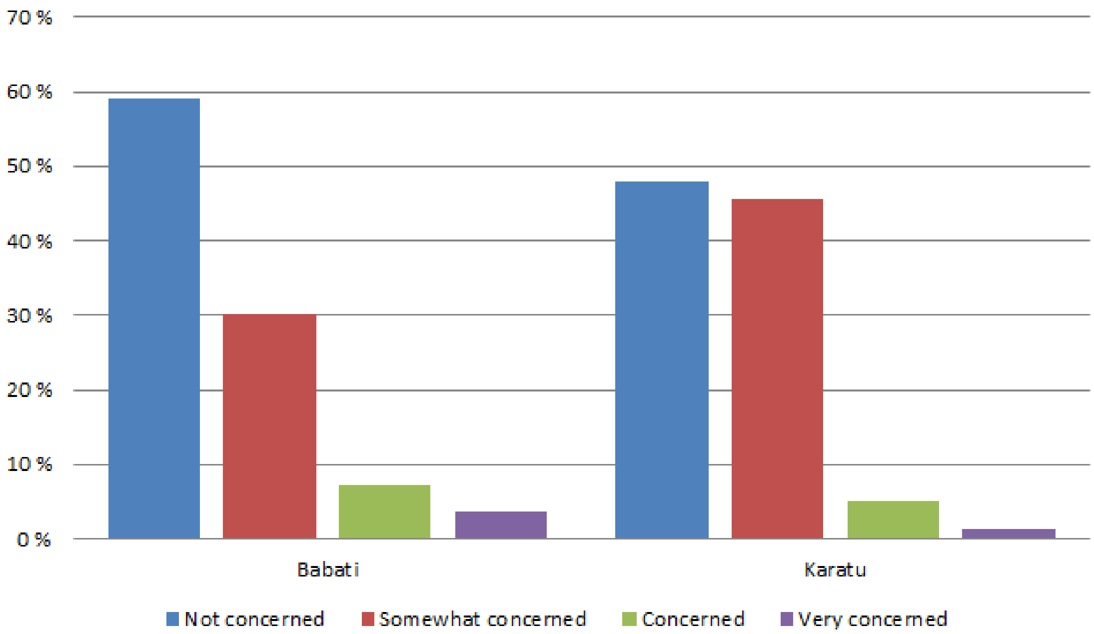


Figure D.4.4. Level of concern associated with intellectual property rights protection and loss of Farmers' Rights due to genetically modified (GM) crops as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p<0.001). Response rate: 100% (805 out of 805 participants).

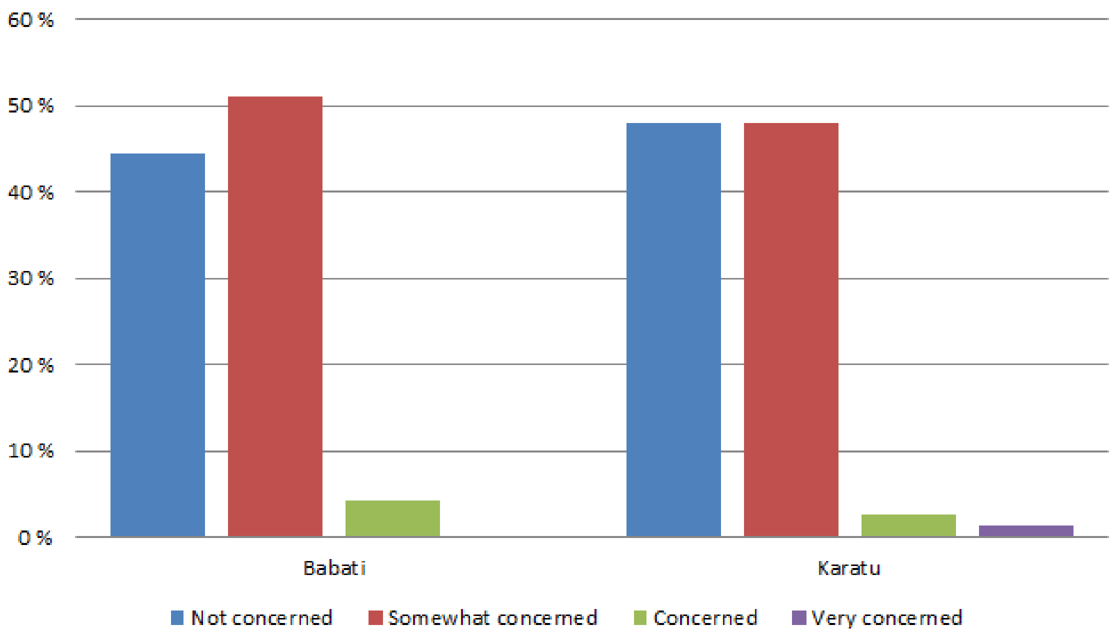


Figure D.4.5. Level of concern associated with consumer reluctance to buy genetically modified (GM) products and hence loss of income as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p<0.05). Response rate: ~98% (788 out of 805 participants).

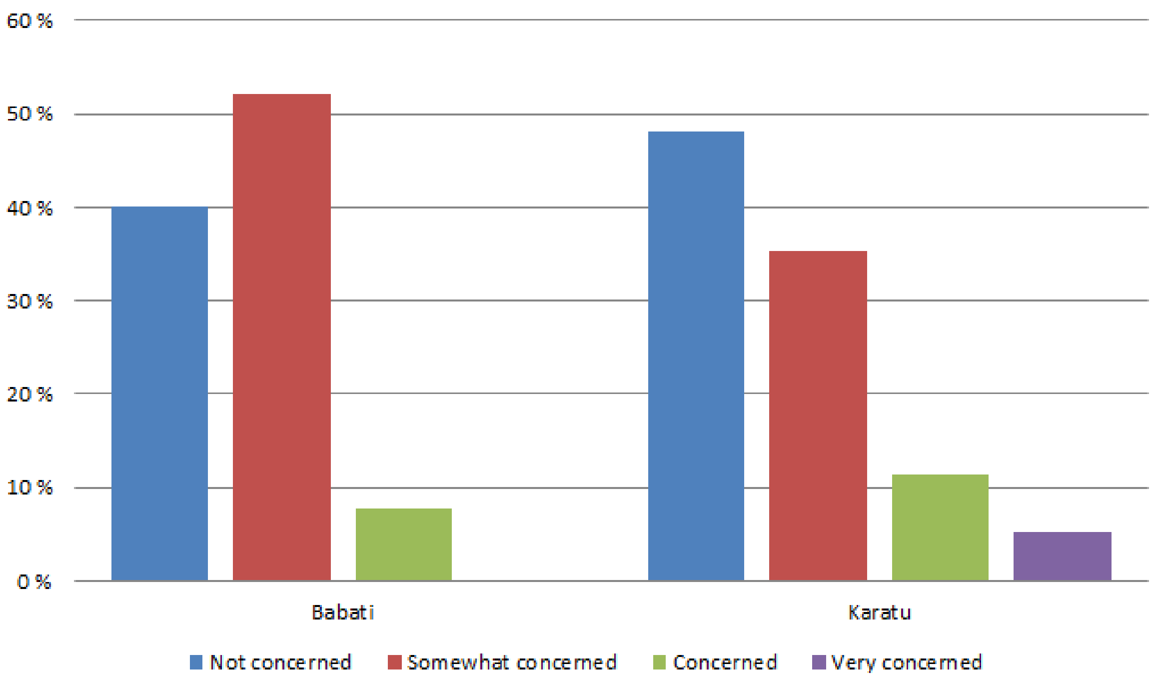
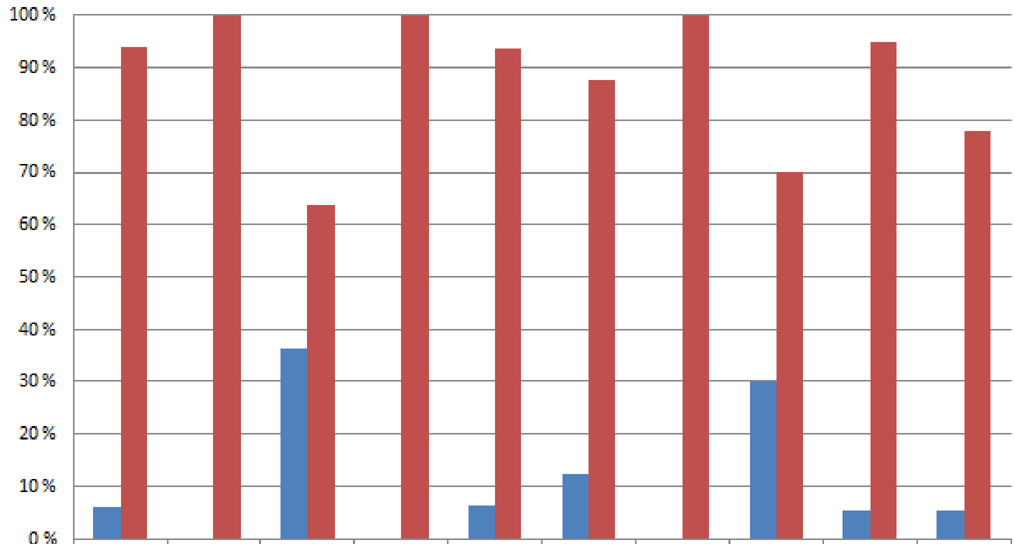


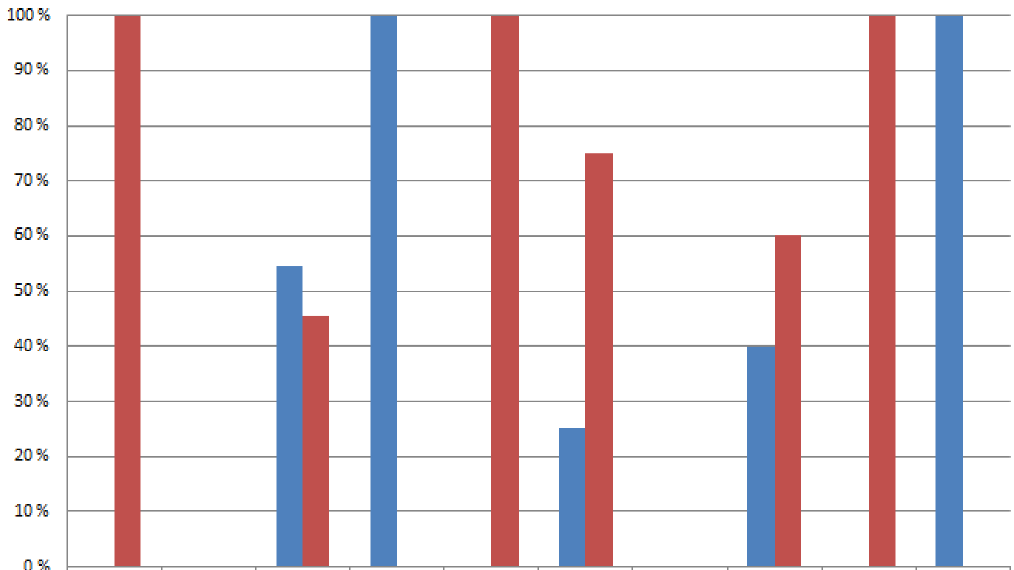
Figure D.4.6. Level of concern associated with low profitability of genetically modified (GM) crop products and hence increased debt as perceived by Tanzanian farmers in the districts of Babati and Karatu (in % of respondents). The association between geographical location (district) and the level of concern was significant (p<0.001). Response rate: ~99% (794 out of 805 participants).

D.5. Ugandan farmer survey: Group-level data



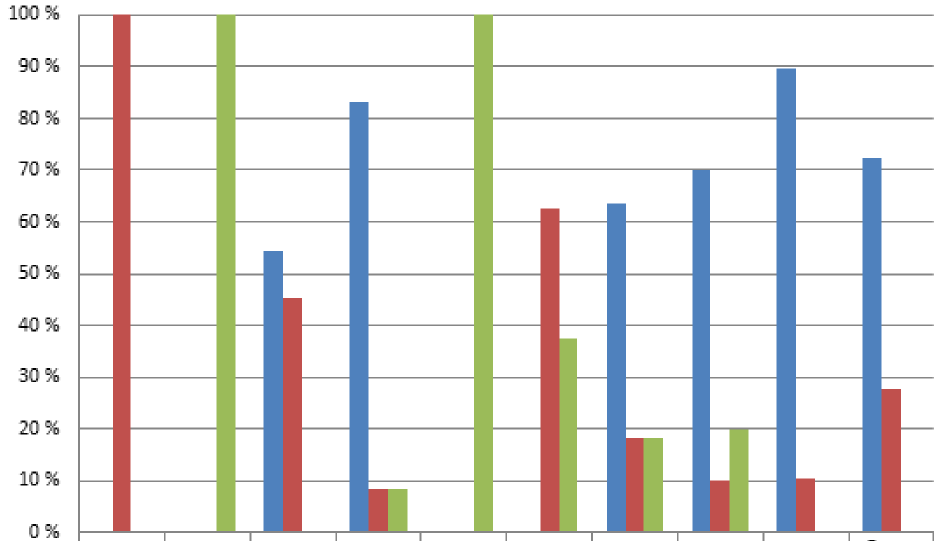
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Aware of GM crops	6 %	0 %	36 %	0 %	6 %	13 %	0 %	30 %	5 %	6 %
Unaware of GM crops	94 %	100 %	64 %	100 %	94 %	88 %	100 %	70 %	95 %	78 %

Figure D.5.1. The level of awareness of genetically modified (GM) crops among Ugandan farmers at the group-level (in % of respondents). Response rate: ~99% (140 out of 142 participants).



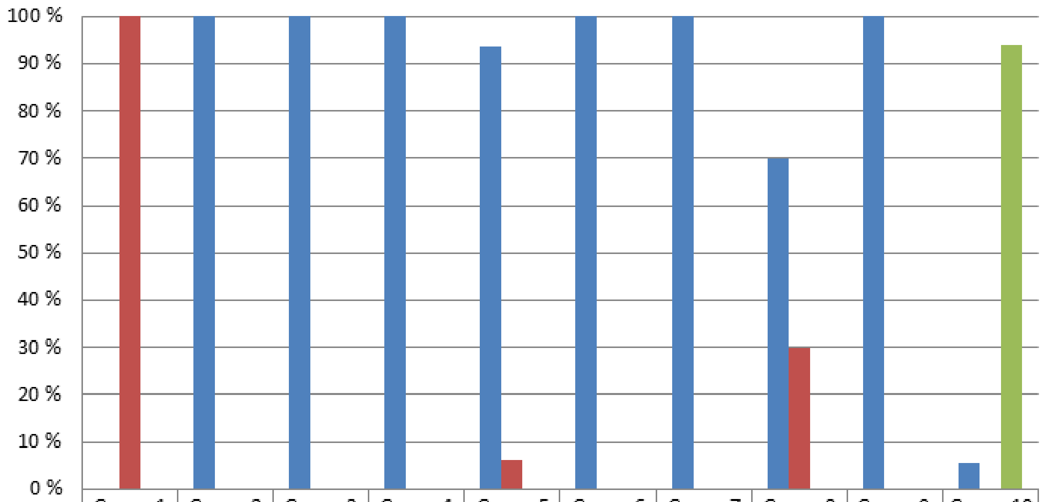
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Favourable	0 %	0 %	55 %	100 %	0 %	25 %	0 %	40 %	0 %	100 %
Unfavourable	100 %	0 %	45 %	0 %	100 %	75 %	0 %	60 %	100 %	0 %

Figure D.5.2. Impressions of genetically modified (GM) crops among Ugandan farmers at the group-level (in % of respondents). Response rate: ~37% (53 out of 142 participants). Please note that the low response rate was because the question was meant to presuppose awareness of GM crops.



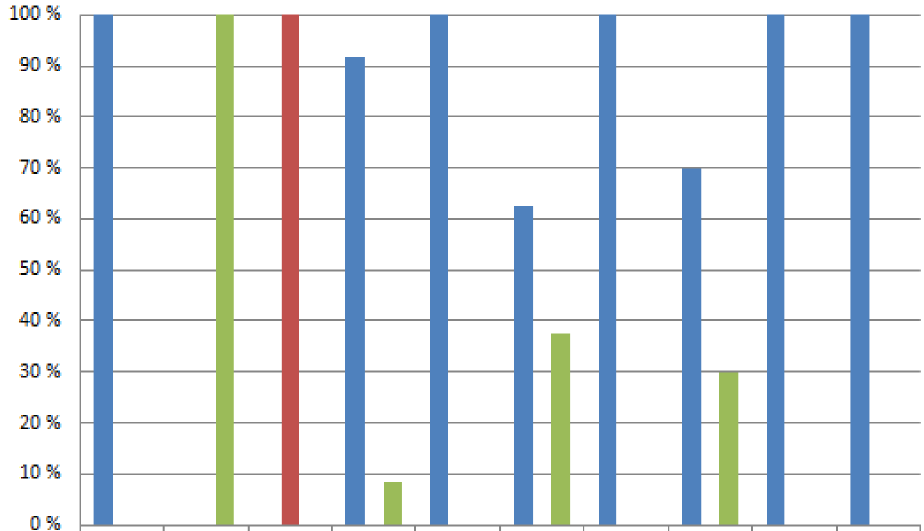
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Find GM crops favourable	0 %	0 %	55 %	83 %	0 %	0 %	64 %	70 %	89 %	72 %
Find GM crops unfavourable	100 %	0 %	45 %	8 %	0 %	63 %	18 %	10 %	11 %	28 %
Do not know	0 %	100 %	0 %	8 %	100 %	38 %	18 %	20 %	0 %	0 %

Figure D.5.3. Percentage of Ugandan farmers at the group level that perceived genetically modified (GM) crops as having a favourable impression among farmers in their area (in % of respondents). Response rate: 100% (142 out of 142 participants).



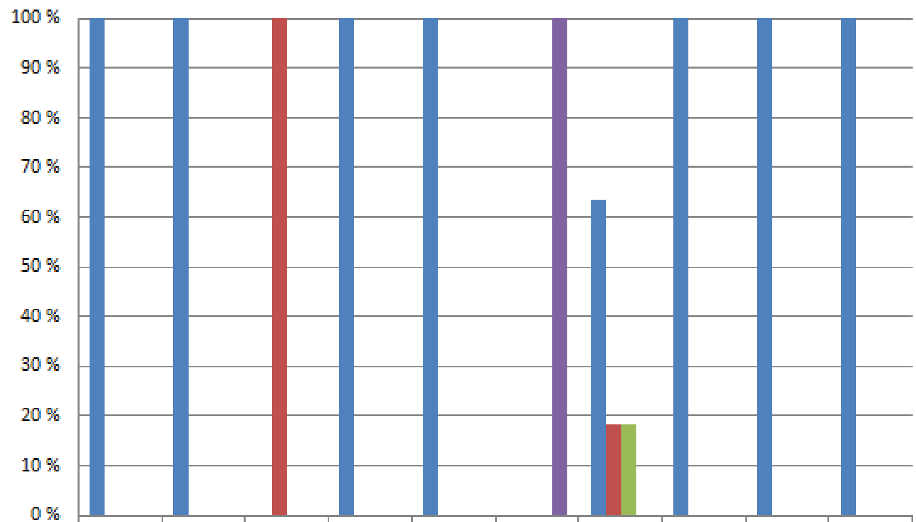
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Would grow	0 %	100 %	100 %	100 %	94 %	100 %	100 %	70 %	100 %	6 %
Would not grow	100 %	0 %	0 %	0 %	6 %	0 %	0 %	30 %	0 %	0 %
No answer	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	94 %

Figure D.5.4. Percentage (%) of Ugandan farmers at the group level that would grow genetically modified (GM) crops if given the opportunity. Response rate: ~88% (125 out of 142 participants).



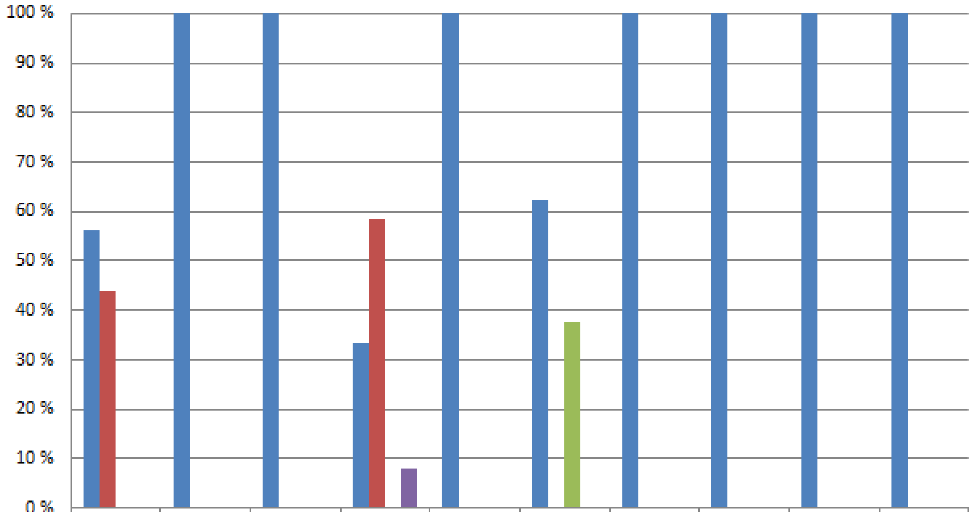
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Help improve quality of life	100 %	0 %	0 %	92 %	100 %	63 %	100 %	70 %	100 %	100 %
Do not help improve quality of life	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
No opinion	0 %	100 %	0 %	8 %	0 %	38 %	0 %	30 %	0 %	0 %

Figure D.5.5. Percentage of Ugandan farmers at the group level that believed genetically modified (GM) crops could help improve the quality of life of farmers (in % of respondents). Response rate: 100% (142 out of 142 participants).



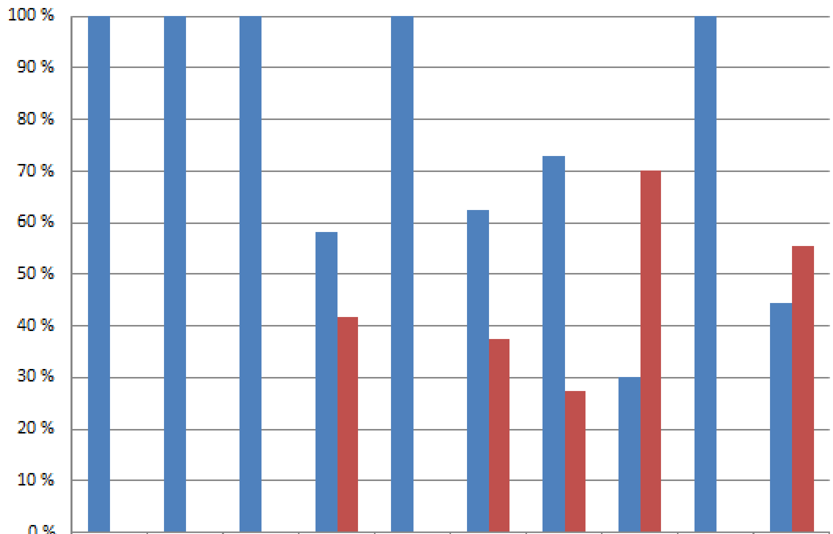
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Support commercialisation	100 %	100 %	0 %	100 %	100 %	0 %	64 %	100 %	100 %	100 %
Do not support commercialisation	0 %	0 %	100 %	0 %	0 %	0 %	18 %	0 %	0 %	0 %
No opinion	0 %	0 %	0 %	0 %	0 %	0 %	18 %	0 %	0 %	0 %
No answer	0 %	0 %	0 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %

Figure D.5.6. Percentage of Ugandan farmers at the group level that supported the commercialisation of genetically modified (GM) crops (in % of respondents). Response rate: ~89% (126 out of 142 participants).



	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Increase in demand	56 %	100 %	100 %	33 %	100 %	63 %	100 %	100 %	100 %	100 %
No increase in demand	44 %	0 %	0 %	58 %	0 %	0 %	0 %	0 %	0 %	0 %
No opinion	0 %	0 %	0 %	0 %	0 %	38 %	0 %	0 %	0 %	0 %
No answer	0 %	0 %	0 %	8 %	0 %	0 %	0 %	0 %	0 %	0 %

Figure D.5.7. Impact of newly acquired information about positive results obtained by genetically modified (GM) crop-adopting farmers in Burkina Faso on demand for GM crops among Ugandan farmers at the group level (in % of respondents). Response rate: ~99% (141 out of 142 participants).



	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Concerned about having to buy new seeds every season	100 %	100 %	100 %	58 %	100 %	63 %	73 %	30 %	100 %	44 %
Not concerned about having to buy new seeds every season	0 %	0 %	0 %	42 %	0 %	38 %	27 %	70 %	0 %	56 %

Figure D.5.8. Concerns associated with seed stewardship among Ugandan farmers at the group-level (in % of respondents). Response rate: 100% (142 out of 142 participants).

D.6. Results from the Monte Carlo simulation model for investigating differences in awareness, impressions and perceptions of genetically modified (GM) crops and related issues on the basis of geographical location (Kenyan counties)

Table D.6. Statistical output from the Monte Carlo simulation model for investigating differences in awareness, impressions, perceptions and acceptance of genetically modified (GM) crops on the basis of geographical location (counties[1]) among Kenyan farmers.

	Chi sq.[2]	Deg.fr.[3]	P-value[4]	Q-value[5]	N[6]
Awareness of GM crops	266.42042	9	0.00000***	0.00000***	1119
Impression of GM crops	259.11279	16	0.00000***	0.00000***	783
Willingness-to-grow GM crops	394.86271	18	0.00000***	0.00000***	1121
Level of concern associated with having to buy new seeds from seed companies every season	720.74622	9	0.00000***	0.00000***	1120
Perceived attitude of farmers in their area towards GM crops	319.23559	18	0.00000***	0.00000***	1099
Level of religious influence on acceptance of GM crops	838.90528	27	0.00000***	0.00000***	1108
Perception of whether GM crops can improve the quality of life of farmers	531.68480	18	0.00000***	0.00000***	1112
Farmer demand for GM crops in response to information about Bt cotton-adopting farmer in Burkina Faso	341.98809	18	0.00000***	0.00000***	1122
Support for commercialisation of GM crops	279.87316	18	0.00000***	0.00000***	1122
Level of concern about potential health effects	1287.80978	27	0.00000***	0.00000***	1093
Level of concern about potential environmental effects	1021.89842	27	0.00000***	0.00000***	1099
Level of concern about religious/cultural concerns	1487.60348	27	0.00000***	0.00000***	1081
Level of concern about IPRs protection for seeds companies and loss of farmer's rights	1397.45675	27	0.00000***	0.00000***	1099
Level of concern about consumer reluctance to buy GM products and hence loss of income	1081.90897	27	0.00000***	0.00000***	1084
Level of concern about low profitability and hence increased debt	1248.84334	27	0.00000***	0.00000***	1072
The degree of challenge associated with low crop productivity and yield	1143.63149	27	0.00000***	0.00000***	1127
The degree of challenge associated with poor quality of produce	947.19520	27	0.00000***	0.00000***	1127
The degree of challenge associated with incidence of crop pest and diseases	735.34179	27	0.00000***	0.00000***	1118
The degree of challenge associated with post-harvest losses	1019.20937	27	0.00000***	0.00000***	1094
The degree of challenge associated with climate change (drought, floods)	1335.25072	27	0.00000***	0.00000***	1103

The degree of challenge associated with inadequate extension services	616.31115	27	0.00000***	0.00000***	1090
The degree of challenge associated with inadequate credit services (unable to afford inputs)	1151.10565	27	0.00000***	0.00000***	1121
The degree of challenge associated with lack of irrigation systems	703.83146	27	0.00000***	0.00000***	1127
The degree of challenge associated with lack of improved technologies	636.04167	27	0.00000***	0.00000***	1129
The degree of challenge associated with poor infrastructure for market access (roads, communication)	1015.33930	27	0.00000***	0.00000***	1114
The degree of challenge associated with debt	647.16418	27	0.00000***	0.00000***	1127
The degree of challenge associated with lack of secure land tenure and property rights	1462.93436	27	0.00000***	0.00000***	1096
The degree of challenge associated with land degradation	915.39984	27	0.00000***	0.00000***	1112
The degree of challenge associated with spending too much time in the field	920.36940	27	0.00000***	0.00000***	1127

[1]The Kenyan counties included Kirinyaga, Kiambu, Nyeri, Tharaka-Nthi, Meru, Muranga, Machakos, Kitui, Makueni and Embu.
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

D.7. Results from the Monte Carlo simulation model for investigating differences in awareness, impressions and perceptions of genetically modified (GM) crops and related issues on the basis of geographical location (Tanzanian districts)

Table D.7. Statistical output from the Monte Carlo simulation model for investigating differences in awareness, impressions, perceptions and acceptance of genetically modified (GM) crops on the basis of geographical location (districts[1]) among Tanzanian farmers.					
	Chi sq.[2]	**Deg.fr.[3]**	**P-value[4]**	**Q-value[5]**	**N[6]**
Awareness of GM crops	5.19122	1	0.02310*	0.02270*	781
Impressions of GM crops	0.99368	1	0.34280	0.31885	88
Willingness-to-grow GM crops	6.59800	1	0.00960**	0.01021*	800
Level of concern associated with having to buy new seeds from seed companies every season	3.10933	1	0.07420	0.07785	800
Perceived attitude of farmers in their area towards GM crops	50.93184	2	0.00000***	0.00000***	803
Level of religious influence on acceptance of GM crops	68.50735	3	0.00000***	0.00000***	804
Perception of whether GM crops can improve the quality of life of farmers	44.56946	2	0.00000***	0.00000***	795
Farmer demand for GM crops in response to information about Bt cotton-adopting farmer in Burkina Faso	9.07448	2	0.00240**	0.01070*	796
Support for commercialisation of GM crops	8.63568	2	0.00740**	0.01333*	796
Level of concern about potential health effects	35.08846	3	0.00000***	0.00000***	798
Level of concern about potential environmental effects	106.96311	3	0.00000***	0.00000***	809
Level of concern about religious/cultural concerns	14.70826	3	0.00100**	0.00208**	798
Level of concern about IPRs protection for seeds companies and loss of farmer's rights	18.74102	3	0.00050**	0.00031**	808
Level of concern about consumer reluctance to buy GM products and hence loss of income	9.25123	3	0.02480*	0.02613*	788
Level of concern about low profitability and hence increased debt	44.77180	3	0.00000***	0.00000***	794
The degree of challenge associated with low crop productivity and yield	30.36184	3	0.00000***	0.00000***	805
The degree of challenge associated with poor quality of produce	4.85508	3	0.17740	0.18272	804
The degree of challenge associated with incidence of crop pest and diseases	43.54620	3	0.00000***	0.00000***	803
The degree of challenge associated with post-harvest losses	18.41454	3	0.00000***	0.00036	803

The degree of challenge associated with climate change (drought, floods)	5.23412	3	0.07140	0.15543	792
The degree of challenge associated with inadequate extension services	20.13381	3	0.00010***	0.00016***	793
The degree of challenge associated with inadequate credit services (unable to afford inputs)	74.02787	3	0.00000***	0.00000***	801
The degree of challenge associated with lack of irrigation systems	182.09826	3	0.00000***	0.00000***	798
The degree of challenge associated with lack of improved technologies	44.30274	3	0.00000***	0.00000***	804
The degree of challenge associated with poor infrastructure for market access (roads, communication)	284.92856	3	0.00000***	0.00000***	801
The degree of challenge associated with debt	12.31942	3	0.00600**	0.00637**	805
The degree of challenge associated with lack of secure land tenure and property rights	16.56500	3	0.00080**	0.00087**	800
The degree of challenge associated with land degradation	52.51974	3	0.00000***	0.00000***	793
The degree of challenge associated with spending too much time in the field	29.18435	3	0.00000***	0.00000***	803

[1]The Tanzanian districts included Karatu (in the Arusha region) and Babati (in the Manyara region).
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

D.8. Results from the Monte Carlo simulation model for investigating differences in awareness, impressions and perceptions of genetically modified (GM) crops and related issues on the basis of geographical location (nationality)

Table D.8. Statistical output from the Monte Carlo simulation model for investigating differences in awareness, impressions, perceptions and acceptance of genetically modified (GM) crops on the basis of nationality[1] among Kenyan, Ugandan and Tanzanian farmers.					
	Chi sq.[2]	**Deg.fr.[3]**	**P-value[4]**	**Q-value[5]**	**Sample size, N[6]**
Awareness of GM crops					
Kenya x Uganda x Tanzania	666.08004	2	0.00000***	0.00000***	2040
Kenya x Uganda	204.85470	1	0.00000***	0.00000***	1259
Kenya x Tanzania	583.76051	1	0.00000***	0.00000***	1900
Tanzania x Uganda	2.81683	1	0.09440	0.09328	921
Impressions of GM crops					
Kenya x Uganda x Tanzania	634.28484	2	0.00000***	0.00000***	1594
Kenya x Uganda	51.49655	1	0.00000***	0.00000***	813
Kenya x Tanzania	632.69734	1	0.00000***	0.00000***	1526
Tanzania x Uganda	28.47616	1	0.00000***	0.00000***	849
Willingness-to-grow GM crops					
Kenya x Uganda x Tanzania	111.09131	2	0.00000***	0.00000***	2024
Kenya x Uganda	0.16297	1	0.67630	0.68644	1224
Kenya x Tanzania	108.73024	1	0.00000***	0.00000***	1894
Tanzania x Uganda	93.12746	1	0.00000***	0.00000***	930
Level of religious influence on acceptance of GM crops					
Kenya x Uganda x Tanzania	352.80895	6	0.00000***	0.00000***	2059
Kenya x Uganda	72.81987	3	0.00000***	0.00000***	1255
Kenya x Tanzania	223.27713	3	0.00000***	0.00000***	1912
Tanzania x Uganda	227.99085	3	0.00000***	0.00000***	951
Perception of whether GM crops can improve the quality of life of farmers					
Kenya x Uganda x Tanzania	163.77301	4	0.00000***	0.00000***	2057
Kenya x Uganda	102.29838	2	0.00000***	0.00000***	1262
Kenya x Tanzania	62.83292	2	0.00000***	0.00000***	1907
Tanzania x Uganda	80.57939	2	0.00000***	0.00000***	945
Farmer demand for GM crops in response to information about Bt cotton-adopting farmer in Burkina Faso					
Kenya x Uganda x Tanzania	91.57940	4	0.00000***	0.00000***	2064
Kenya x Uganda	12.15061	2	0.00420**	0.00230***	1268
Kenya x Tanzania	86.58439	2	0.00000***	0.00000***	1918
Uganda x Tanzania	78.83858	2	0.00000***	0.00000***	942
Support for commercialisation of GM crops					
Kenya x Uganda x Tanzania	96.41774	4	0.00000***	0.00000***	2044
Kenya x Uganda	0.24961	2	0.88720	0.88267	1248
Kenya x Tanzania	96.75651	2	0.00000***	0.00000***	1918
Uganda x Tanzania	69.22835	2	0.00000***	0.00000***	922
Level of concern about potential health effects					
Kenya x Uganda x Tanzania	1174.73185	6	0.00000***	0.00000**	2017

Kenya x Uganda	22.92313	3	0.00000***	0.00000**	1219
Kenya x Tanzania	1061.18792	3	0.00000***	0.00004**	1891
Uganda x Tanzania	610.89187	3	0.00000***	0.00000**	924
Level of concern about potential environmental effects					
Kenya x Uganda x Tanzania	1163.41468	6	0.00000***	0.00000***	1034
Kenya x Uganda	26.03799	3	0.00000***	0.00000***	1225
Kenya x Tanzania	1065.65012	3	0.00010***	0.00001***	1908
Uganda x Tanzania	657.21887	3	0.00000***	0.00000***	935
Level of concern about religious/cultural concerns					
Kenya x Uganda x Tanzania	606.00955	6	0.00000***	0.00000***	2005
Kenya x Uganda	28.37348	3	0.00000***	0.00000***	1207
Kenya x Tanzania	566.44674	3	0.00000***	0.00000***	1879
Uganda x Tanzania	264.51066	3	0.00000***	0.00000***	924
Level of concern about IPRs protection for seeds companies and loss of Farmers' rights					
Kenya x Uganda x Tanzania	911.86486	6	0.00000***	0.00000***	2033
Kenya x Uganda	49.08582	3	0.00000***	0.00000***	1225
Kenya x Tanzania	776.51439	3	0.00000***	0.00000***	1907
Uganda x Tanzania	611.82195	3	0.00000***	0.00000***	934
Level of concern about consumer reluctance to buy GM products and hence loss of income					
Kenya x Uganda x Tanzania	1279.09718	6	0.00000***	0.00000***	1998
Kenya x Uganda	27.33473	3	0.00010***	0.00001***	1210
Kenya x Tanzania	1152.17692	3	0.00000***	0.00000***	1872
Uganda x Tanzania	763.31530	3	0.00000***	0.00000***	914
Level of concern about low profitability and hence increased debt					
Kenya x Uganda x Tanzania	1097.36502	6	0.00000***	0.00000***	1992
Kenya x Uganda	30.34224	3	0.00000***	0.00000***	1198
Kenya x Tanzania	977.37458	3	0.00000***	0.00000***	1866
Uganda x Tanzania	707.49321	3	0.00000***	0.00000***	920
The degree of challenge associated with low crop productivity and yield					
Kenya x Uganda x Tanzania	239.49463	6	0.00000***	0.00000***	2064
Kenya x Uganda	8.97218	3	0.02820*	0.02966*	1259
Kenya x Tanzania	210.14747	3	0.00000***	0.00000***	1932
Uganda x Tanzania	63.61998	3	0.00000***	0.00000***	937
The degree of challenge associated with poor quality of produce					
Kenya x Uganda x Tanzania	464.18710	6	0.00000***	0.00000***	2063
Kenya x Uganda	20.96252	3	0.00050***	0.00011***	1259
Kenya x Tanzania	406.66250	3	0.00000***	0.00000***	1931
Uganda x Tanzania	184.65470	3	0.00000***	0.00000***	936
The degree of challenge associated with incidence of crop pest and diseases					
Kenya x Uganda x Tanzania	475.85247	6	0.00000***	0.00000***	2053
Kenya x Uganda	20.96252	3	0.00000***	0.00011***	1250
Kenya x Tanzania	403.88950	3	0.00000***	0.00000***	1921
Uganda x Tanzania	146.85603	3	0.00000***	0.00000***	935
The degree of challenge associated with post-harvest losses					
Kenya x Uganda x Tanzania	551.54300	6	0.00000***	0.00000***	2029
Kenya x Uganda	99.04947	3	0.00000***	0.00000***	1226
Kenya x Tanzania	523.02498	3	0.00000***	0.00000***	1897
Uganda x Tanzania	129.01337	3	0.00000***	0.00000***	935

The degree of challenge associated with climate change (drought, floods)					
Kenya x Uganda x Tanzania	260.72289	6	0.00000***	0.00000***	2027
Kenya x Uganda	69.75874	3	0.00000***	0.00000***	1235
Kenya x Tanzania	182.39917	3	0.00000***	0.00000***	1895
Uganda x Tanzania	56.83058	3	0.00000***	0.00000***	924
The degree of challenge associated with inadequate extension services					
Kenya x Uganda x Tanzania	499.16172	6	0.00000***	0.00000***	2015
Kenya x Uganda	34.44689	3	0.00000***	0.00000***	1222
Kenya x Tanzania	402.26779	3	0.00000***	0.00000***	1883
Uganda x Tanzania	219.38400	3	0.00000***	0.00000***	925
The degree of challenge associated with inadequate credit services (unable to afford inputs)					
Kenya x Uganda x Tanzania	708.73075	6	0.00000***	0.00000***	2054
Kenya x Uganda	40.89187	3	0.00000***	0.00000***	1253
Kenya x Tanzania	684.42095	3	0.00000***	0.00000***	1922
Uganda x Tanzania	190.81647	3	0.00000***	0.00000***	933
The degree of challenge associated with lack of irrigation systems					
Kenya x Uganda x Tanzania	197.65585	6	0.00000***	0.00000***	2057
Kenya x Uganda	103.39854	3	0.00000***	0.00000***	1259
Kenya x Tanzania	69.67725	3	0.00000***	0.00000***	1925
Uganda x Tanzania	111.10276	3	0.00000***	0.00000***	930
The degree of challenge associated with lack of improved technologies					
Kenya x Uganda x Tanzania	377.41475	6	0.00000***	0.00000***	2065
Kenya x Uganda	105.65598	3	0.00000***	0.00000***	1261
Kenya x Tanzania	256.48017	3	0.00000***	0.00000***	1933
Uganda x Tanzania	86.99298	3	0.00000***	0.00000***	936
The degree of challenge associated with poor infrastructure for market access (roads, communication)					
Kenya x Uganda x Tanzania	310.55725	6	0.00000***	0.00000***	2047
Kenya x Uganda	6.51582	3	0.09570	0.08904	1246
Kenya x Tanzania	285.17904	3	0.00000***	0.00000***	1915
Uganda x Tanzania	126.20168	3	0.00000***	0.00000***	933
The degree of challenge associated with debt					
Kenya x Uganda x Tanzania	785.04062	6	0.00000***	0.00000***	2064
Kenya x Uganda	32.47593	3	0.00010***	0.00000***	1259
Kenya x Tanzania	677.25760	3	0.00000***	0.00000***	1932
Uganda x Tanzania	459.53505	3	0.00000***	0.00000***	937
The degree of challenge associated with lack of secure land tenure and property rights					
Kenya x Uganda x Tanzania	741.70774	6	0.00000***	0.00000***	2028
Kenya x Uganda	170.00990	3	0.00000***	0.00000***	1228
Kenya x Tanzania	434.79011	3	0.00000***	0.00000***	1896
Uganda x Tanzania	593.57227	3	0.00000***	0.00000***	932
The degree of challenge associated with land degradation					
Kenya x Uganda x Tanzania	375.84077	6	0.00000***	0.00000***	2037
Kenya x Uganda	222.10969	3	0.00000***	0.00000***	1244
Kenya x Tanzania	93.09151	3	0.00000***	0.00000***	1905
Uganda x Tanzania	247.22306	3	0.00000***	0.00000***	1905
The degree of challenge associated with spending too much time in the field					
Kenya x Uganda x Tanzania	556.42563	6	0.00000***	0.00000***	2046
Kenya x Uganda	7.75969	3	0.04980	0.05125	1243

Kenya x Tanzania	538.91074	3	0.00000***	0.00000***	1930
Uganda x Tanzania	248.83035	3	0.00000***	0.00000***	919

[1] Kenya, Uganda and Tanzania.
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
*** Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

D.9. Simulation model for estimating correlations between demographic factors, awareness, impressions, perceptions and acceptance of genetically modified (GM) crops among Kenyan, Ugandan and Tanzanian farmers

D.9.1. Kenyan farmers

Table D.9.1. Statistical output of the Monte Carlo simulation model for estimating correlations between demographic factors, awareness, impressions, perceptions and acceptance of genetically modified (GM) crops among Kenyan farmers.					
Sex.					
Correlation between the fraction of female farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)[1]	**Chi(X2)**[2]	**Corr(X1, X2), c**[3]	**LCorr(X1, X2), logc**[4]	**N**[5]
	464.48315	935.00441	-0.04007	+0.00310	72
Significance, P[5]	0.00000***	0.00000***	0.74240	0.98120	
Correlation between the fraction of male farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	462.23865	935.00441	+0.03836	-0.00395	72
Significance, P	0.00000***	0.00000***	0.75550	0.97790	
Correlation between the fraction of female farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	361.46664	542.08465	-0.03859	+0.01397	57
Significance, P	0.00000***	0.00000***	0.77970	0.92130	
Correlation between the fraction of male farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	359.16408	542.08465	+0.03161	-0.01432	57
Significance, P	0.00000***	0.00000***	0.81820	0.91530	
Correlation between the fraction of female farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	464.48315	736.39544	-0.04375	-0.13371	72
Significance, P	0.00000***	0.00000***	0.72210	0.29040	
Correlation between the fraction of male farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	462.23865	736.39544	+0.03625	+0.13350	72
Significance, P	0.00000***	0.00000***	0.76460	0.28610	
Correlation between the fraction of female farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	464.48315	786.03384	+0.05904	+0.03328	72
Significance, P	0.00000***	0.00000***	0.63520	0.79720	
Correlation between the fraction of male farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	462.23865	786.03384	-0.06946	-0.03547	72

Significance, P	0.00000***	0.00000***	0.57440	0.78690	
Education.					
Correlation between the fraction of farmers with primary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	407.28241	799.54527	-0.54605	-0.48788	59
Significance, P	0.00000***	0.00000***	0.00000***	0.00060***	
Correlation between the fraction of farmers with secondary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	329.32371	799.54527	+0.47455	+0.35740	59
Significance, P	0.00000***	0.00000***	0.00030**	0.00990***	
Correlation between the fraction of farmers with higher education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	417.55115	799.54527	+0.21411	+0.18399	59
Significance, P	0.00000***	0.00000***	0.11170	0.17990	
Correlation between the fraction of farmers with primary education and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	235.55190	417.49388	-0.34727	-0.29636	44
Significance, P	0.00000***	0.00000***	0.02250*	0.05600	
Correlation between the fraction of farmers with secondary education and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	205.04805	417.49388	+0.30187	+0.29221	44
Significance, P	0.00000***	0.00000***	0.04890*	0.05930	
Correlation between the fraction of farmers with higher education and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	276.73126	417.49388	+0.08536	-0.03141	44
Significance, P	0.00000***	0.00000***	0.58320	0.84810	
Correlation between the fraction of farmers with primary education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	407.28241	610.91678	-0.11631	-0.09138	59
Significance, P	0.00000***	0.00000***	0.39280	0.50440	
Correlation between the fraction of farmers with secondary education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	329.32371	610.91678	+0.06695	+0.10814	59
Significance, P	0.00000***	0.00000***	0.62230	0.42950	
Correlation between the fraction of farmers with higher education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	454.34340	660.45484	+0.08233	+0.04222	59
Significance, P	0.00000***	0.00000***	0.53680	0.76390	
Correlation between the fraction of farmers with primary education and the fraction of farmers that					

supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	407.28241	640.37914	-0.08603	-0.09642	59
Significance, P	0.00000***	0.00000***	0.52970	0.48300	
Correlation between the fraction of farmers with secondary education and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	329.32371	640.37914	+0.07693	+0.15349	59
Significance, P	0.00000***	0.00000***	0.57230	0.27020	
Correlation between the fraction of farmers with higher education and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	454.34340	695.61761	+0.02453	-0.02675	59
Significance, P	0.00000***	0.00000***	0.85240	0.84350	
Marital status.					
Correlation between the fraction of single farmers and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	271.36274	505.64322	-0.01211	-0.03442	51
Significance, P	0.00000***	0.00000***	0.92940	0.83080	
Correlation between the fraction of married farmers and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	283.94666	505.64322	+0.03210	+0.03757	51
Significance, P	0.00000***	0.00000***	0.81910	0.81460	
Correlation between the fraction of single farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	339.07702	648.36131	+0.03378	+0.04664	65
Significance, P	0.00000***	0.00000***	0.79970	0.72960	
Correlation between the fraction of married farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	358.54708	648.36131	-0.04178	-0.10312	65
Significance, P	0.00000***	0.00000***	0.74970	0.45260	
Correlation between the fraction of single farmers and the fraction of farmers that supported the commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	339.07702	705.70779	-0.03154	-0.08827	65
Significance, P	0.00000***	0.00000***	0.80240	0.51210	
Correlation between the fraction of married farmers and supporting the commercialisation.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	358.54708	705.7077	+0.03051	+0.03041	65
Significance, P	0.00000***	0.00000***	0.81550	0.81980	
Cultural leaning.					
Correlation between the fraction of culturally liberal farmers and the fraction of farmers with the fraction of farmers with a favourable impression of GM crops.					

	Chi(X1)	Chi(X2)	Corr(X1, X2)	LCorr(X1, X2)	Sample size, N
	750.64311	511.76754	+0.06279	+0.07077	56
Significance, P	0.00000***	0.00000***	0.65440	0.58330	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	677.01479	511.76754	-0.00098	-0.00001	56
Significance, P	0.00000***	0.00000***	0.99500	0.99990	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	298.31541	511.76754	-0.27896	-0.26848	56
Significance, P	0.00000***	0.00000***	0.03730*	0.03600*	
Correlation between the fraction of culturally liberal farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	1041.45481	708.89326	+0.05219	+0.06258	71
Significance, P	0.00000***	0.00000***	0.66280	0.63890	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	960.69018	708.89326	-0.00129	+0.00503	71
Significance, P	0.00000***	0.00000***	0.99290	0.96970	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	422.33090	708.89326	-0.24718	-0.25786	71
Significance, P	0.00000***	0.00000***	0.04600*	0.01960*	
Correlation between the fraction of culturally liberal farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	1041.45481	757.78326	+0.12800	+0.16606	71
Significance, P	0.00000***	0.00000***	0.29630	0.19580	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	960.69018	757.78326	-0.07057	-0.10849	71
Significance, P	0.00000***	0.00000***	0.56780	0.40770	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	422.33090	757.78326	-0.25963	-0.19269	71
Significance, P	0.00000***	0.00000***	0.03270*	0.10250	
Effect of awareness.					
Correlation between the fraction of farmers aware of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**

	935.00441	892.61815	+0.04494	+0.01335	72
Significance, P	0.00000***	0.00000***	0.71050	0.91540	
Correlation between the fraction of unaware farmers aware of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	946.60812	892.61815	-0.03156	+0.01749	72
Significance, P	0.00000***	0.00000***	0.80210	0.89770	
Effect of prior impression of GM crops on perceptions and acceptance of the technology.					
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	536.65046	609.29664	+0.58886	+0.58314	56
Significance, P	0.00000***	0.00000***	0.00000***	0.00320**	
Correlation between the fraction of farmers having an unfavourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having an unfavourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	543.67759	528.90286	+0.78592	+0.73315	56
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	539.43705	639.63298	+0.52467	+0.50544	56
Significance, P	0.00000***	0.00000***	0.00000***	0.00290***	
Correlation between the fraction of farmers having an unfavourable impression of GM crops the fraction of farmers that did not considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	547.27058	681.76392	+0.57139	+0.51884	56
Significance, P	0.00000***	0.00000***	0.00000***	0.00050***	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	542.08465	514.75591	+0.70685	+0.72016	57
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that were not willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	550.26524	606.81493	+0.82900	+0.79022	57
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	557.07342	586.84226	+0.56402	+0.58040	58
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers with an unfavourable impression of GM crops and the fraction of farmers that did not support commercialisation of GM crops.					

	Chi(X1)	Chi(X2)	Corr(X1, X2)	LCorr(X1, X2)	Sample size, N
	550.26524	642.03099	+0.67358	+0.64811	58
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	542.08465	602.41499	+0.54510	+0.53067	57
Significance, P	0.00000***	0.00000***	0.00000***	0.00010***	
Correlation between the fraction of farmers having an unfavourable impression of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	550.26524	602.41499	-0.65196	-0.57821	57
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Effect of increase in demand for GM crops on support for commercialisation of GM crops.					
Correlation between the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	892.61815	786.03384	+0.94062	+0.90143	72
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	
Correlation between the fraction of farmers that did not report of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso and the fraction of farmers that did not support commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	970.82710	866.96386	+0.95377	+0.92136	72
Significance, P	0.00000***	0.00000***	0.00000***	0.00000***	

[1] Chi(X1) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
[2] Chi(X2) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
Note: The p-values of Chi(X1) and Chi(X2) are part of the estimation for group equality, i.e. whether the groups share a common probability of success (tested for both the q and p-value).
[3] Corr(X1, X2) = c = the correlation value between column X1 and column X2.
[4] LCorr(X1, X2) = logc = the correlation value between column X1 and column X2 for logit transformed data.
[5] Sample size, N = the number of rows (i.e. number of farmer groups).
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

D.9.2. Ugandan farmers

Table D.9.2. Statistical output of the Monte Carlo simulation model for estimating correlations between demographic factors, awareness, impressions, perceptions and acceptance of genetically modified (GM) crops among Ugandan farmers.					
Sex.					
Correlation between the fraction of female farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)[1]	**Chi(X2)[2]**	**Corr(X1, X2), c[3]**	**LCorr(X1, X2), logc[4]**	**N[5]**
	27.51124	19.81040	-0.74136	-0.64659	10
Significance, P[5]	0.00070***	0.01730**	0.00430**	0.02130*	
Correlation between the fraction of male farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	27.51124	19.81040	+0.74136	+0.64659	10
Significance, P	0.00110**	0.01720*	0.00330**	0.02150*	
Correlation between the fraction of female farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	23.74977	66.58991	+0.00114	+0.03688	8
Significance, P	0.00060***	0.00000***	0.99810	0.91860	
Correlation between the fraction of male farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	23.74977	66.58991	-0.00114	-0.03688	8
Significance, P	0.00030***	0.00000***	0.99740	0.92690	
Correlation between the fraction of female farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	27.51124	121.33284	-0.06968	-0.09568	10
Significance, P	0.00080***	0.00000***	0.83080	0.76750	
Correlation between the fraction of male farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	27.51124	121.33284	+0.06968	+0.09568	10
Significance, P	0.00070***	0.00000***	0.83590	0.77470	
Correlation between the fraction of female farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	25.63152	101.72875	+0.70724	+0.69232	9
Significance, P	0.00070***	0.00000***	0.01220*	0.01850*	
Correlation between the fraction of male farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	25.63152	101.72875	-0.70724	-0.69232	9
Significance, P	0.00110***	0.00000***	0.01230*	0.01740*	
Education.					
Correlation between the fraction of farmers with primary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**

	29.32706	9.81040	-0.58491	-0.55016	10
Significance, P	0.00020***	0.01970*	0.04700*	0.06760	
Correlation between the fraction of farmers with secondary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	11.70221	19.81040	+0.57941	+0.66646	10
Significance, P	0.23870	0.01880*	0.04540*	0.01770*	
Correlation between the fraction of farmers with higher education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	19.94424	19.81040	+0.54071	+0.34204	10
Significance, P	0.01910*	0.01680*	0.06650	0.28640	
Correlation between the fraction of farmers with primary education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	27.45350	66.58991	+0.13784	+0.20095	8
Significance, P	0.00010***	0.00000***	0.70940	0.59360	
Correlation between the fraction of farmers with secondary education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	9.34958	66.58991	-0.21646	-0.24186	8
Significance, P	0.22060	0.00000***	0.55560	0.50810	
Correlation between the fraction of farmers with higher education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	15.25483	66.58991	+0.17094	+0.06846	8
Significance, P	0.02770*	0.00000***	0.64690	0.86100	
Correlation between the fraction of farmers with primary education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	29.32706	121.33284	+0.20989	+0.32303	10
Significance, P	0.00070***	0.00000***	0.53420	0.31580	
Correlation between the fraction of farmers with secondary education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	11.70221	121.33284	-0.11275	-0.29659	10
Significance, P	0.23420	0.00000***	0.72810	0.35500	
Correlation between the fraction of farmers with higher education and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	19.94424	121.33284	+0.12342	-0.05483	10
Significance, P	0.01480*	0.00000***	0.70890	0.87090	
Correlation between the fraction of farmers with primary education and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	25.66019	101.72875	+0.38289	+0.36681	9
Significance, P	0.00080***	0.00000***	0.25800	0.27120	
Correlation between the fraction of farmers with secondary education and the fraction of farmers					

that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	9.31697	101.72875	-0.16895	-0.10200	9
Significance, P	0.32910	0.00000***	0.63220	0.77780	
Correlation between the fraction of farmers with higher education and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	20.42958	101.72875	-0.63962	-0.54143	9
Significance, P	0.00780**	0.00000***	0.03040*	0.07990	
Marital status.					
Correlation between the fraction of single farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	18.81207	66.58991	-0.22687	-0.52363	8
Significance, P	0.00720**	0.00000***	0.54660	0.12690	
Correlation between the fraction of married farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	66.58991	18.81207	+0.22687	+0.52363	8
Significance, P	0.00740**	0.00000***	0.55430	0.12650	
Correlation between the fraction of single farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	18.71393	21.33284	+0.15554	-0.16212	10
Significance, P	0.02590*	0.00000***	0.63660	0.62410	
Correlation between the fraction of married farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	19.16433	121.33284	-0.17840	+0.14972	10
Significance, P	0.01980*	0.00000***	0.58730	0.65130	
Correlation between the fraction of single farmers and the fraction of farmers that supported the commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	16.96670	101.72875	-0.40414	-0.27751	9
Significance, P	0.02730*	0.00000***	0.23010	0.41790	
Correlation between the fraction of married farmers and the fraction of farmers that supported the commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	25.63152	101.72875	-0.70724	-0.69232	9
Significance, P	0.00060***	0.00000***	0.01050*	0.01600*	
Cultural leaning.					
Correlation between the fraction of culturally liberal farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	111.54174	66.58991	-0.25752	-0.28268	8
Significance, P	0.00000***	0.00000***	0.49330	0.42810	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers with a favourable impression of GM crops.					

	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	114.35945	66.58991	+0.40478	+0.64418	8
Significance, P	0.00000***	0.00000***	0.26350	0.04050*	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	110.78279	66.58991	-0.24837	-0.44022	8
Significance, P	0.00000***	0.00000***	0.51170	0.20560	
Correlation between the fraction of culturally liberal farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	134.48733	121.33284	+0.19921	+0.27955	10
Significance, P	0.00000***	0.00000***	0.53810	0.37870	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	138.35713	121.33284	-0.03361	+0.08888	10
Significance, P	0.00000***	0.00000***	0.92250	0.79560	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	135.05647	121.33284	-0.09119	-0.24203	10
Significance, P	0.00000***	0.00000***	0.78720	0.45980	
Correlation between the fraction of culturally liberal farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	119.19211	101.72875	+0.07342	-0.11033	9
Significance, P	0.00000***	0.00000***	0.83650	0.76210	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	122.24929	101.72875	+0.10418	-0.05702	9
Significance, P	0.00000***	0.00000***	0.76610	0.87190	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	119.31818	101.72875	-0.15467	-0.01534	9
Significance, P	0.00000***	0.00000***	0.66020	0.96380	
Effect of awareness.					
Correlation between the fraction of farmers aware of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	19.81040	59.83494	+0.24171	+0.12409	10
Significance, P	0.01770*	0.00000***	0.45770	0.74490	
Correlation between the fraction of unaware farmers aware of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					

	Chi(X1)	Chi(X2)	Corr(X1, X2)	LCorr(X1, X2)	Sample size, N
	21.42421	59.83494	-0.35281	-0.35262	10
Significance, P	0.01060*	0.00000***	0.27180	0.25960	
Effect of prior impression of GM crops and perceptions and acceptance of the technology.					
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	66.58991	69.92472	+0.36412	+0.38955	8
Significance, P	0.00000***	0.00000***	0.31380	0.27920	
Correlation between the fraction of farmers having an unfavourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having an unfavourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	43.08918	55.67731	+0.16490	+0.12200	8
Significance, P	0.00000***	0.00000***	0.68610	0.75960	
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	66.58991	71.74616	-0.34970	-0.49469	8
Significance, P	0.00000***	0.00000***	0.33400	0.15200	
Correlation between the fraction of farmers having an unfavourable impression of GM crops the fraction of farmers that did not considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	43.08918	100.00000	+0.20862	+0.24994	8
Significance, P	0.00000***	0.00000***	0.60190	0.52990	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that were willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	66.58991	99.49997	+0.38476	+0.38698	8
Significance, P	0.00000***	0.00000***	0.29080	0.28940	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that were not willing to grow GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	43.08918	81.01563	-0.17260	+0.01463	8
Significance, P	0.00000***	0.00000***	0.66950	0.97310	
Correlation between the fraction of farmers with a favourable impression of GM crops and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	67.23382	102.00000	-0.25496	-0.19070	8
Significance, P	0.00000***	0.00000***	0.53040	0.64650	
Correlation between the fraction of farmers with an unfavourable impression of GM crops and the fraction of farmers that did not support commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	26.76258	84.00000	+0.39953	+0.36542	
Significance, P	0.00010***	0.00000***	0.34150	0.38880	
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information					

about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	66.58991	47.22365	-0.45023	-0.33530	8
Significance, P	0.00000***	0.00000***	0.19820	0.35730	
Correlation between the fraction of farmers having an unfavourable impression of GM crops and the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	43.08918	37.58790	+0.18245	+0.31906	8
Significance, P	0.00000***	0.00000***	0.66190	0.41930	
Effect of increase in demand for GM crops and the fraction of farmers that supported commercialisation of GM crops.					
Correlation between the fraction of farmers that reported of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso and the fraction of farmers that supported commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	63.02838	101.72875	-0.21851	-0.23350	9
Significance, P	0.00000***	0.00000***	0.52670	0.52200	
Correlation between the fraction of farmers that did not report of an increase in demand for GM crops in response to information about GM crop-adopting farmers in Burkina Faso and the fraction of farmers that did not support commercialisation of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	56.60156	108.31524	-0.19720	-0.22723	9
Significance, P	0.00000***	0.00000***	0.57700	0.52970	

[1] Chi(X1) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
[2] Chi(X2) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
Note: The p-values of Chi(X1) and Chi(X2) are part of the estimation for group equality, i.e. whether the groups share a common probability of success (tested for both the q and p-value).
[3] Corr(X1, X2) = c = the correlation value between column X1 and column X2.
[4] LCorr(X1, X2) = logc = the correlation value between column X1 and column X2 for logit transformed data.
[5] Sample size, N = the number of rows (i.e. number of farmer groups).
***Indicate statistical significance at the 5% level.**
****Indicate statistical significance at the 1% level.**
*****Indicate statistical significance at the 0.1% level.**
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

D.9.3. Tanzanian farmers

Table D.9.3. Statistical output of the Monte Carlo simulation model for estimating correlations between demographic factors, awareness, impressions, perceptions and acceptance of genetically modified (GM) crops Tanzanian farmers.					
Sex.					
Correlation between the fraction of female farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)[1]	**Chi(X2)**[2]	**Corr(X1, X2), c**[3]	**LCorr(X1, X2), logc**[4]	**N**[5]
	210.80108	281.83486	-0.08080	-0.03163	84
Significance, P[5]	0.00000***	0.00000***	0.48280	0.80910	
Correlation between the fraction of male farmers and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	196.86297	281.83486	+0.10750	+0.07261	84
Significance, P	0.00000***	0.00000***	0.35120	0.56500	
Correlation between the fraction of female farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	199.37914	257.83206	-0.20878	-0.10744	78
Significance, P	0.00000***	0.00000***	0.07930	0.39960	
Correlation between the fraction of male farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	185.20789	257.83206	+0.23769	+0.14329	78
Significance, P	0.00000***	0.00000***	0.04420*	0.25750	
Education.					
Correlation between the fraction of farmers with primary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	133.49792	285.99137	+0.07735	+0.02342	85
Significance, P	0.00060***	0.00000***	0.49590	0.83860	
Correlation between the fraction of farmers with secondary education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	106.17633	285.99137	-0.17146	-0.13830	85
Significance, P	0.05010	0.00000***	0.12790	0.22700	
Correlation between the fraction of farmers with higher education and the fraction of farmers aware of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	138.72425	285.99137	+0.18295	+0.23360	85
Significance, P	0.00120**	0.00000***	0.10530	0.03170*	
Correlation between the fraction of farmers with primary education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	123.82180	257.83206	+0.03938	-0.02668	78
Significance, P	0.00060***	0.00000***	0.73920	0.82220	
Correlation between the fraction of farmers with secondary education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**

	95.17464	257.83206	-0.10424	-0.04972	78
Significance, P	0.07660	0.00000***	0.38350	0.66320	
Correlation between the fraction of farmers with higher education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	133.24219	257.83206	+0.17783	+0.20348	78
Significance, P	0.00080***	0.00000***	0.12700	0.06930	
Correlation between the fraction of farmers with primary education and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	133.49792	278.14500	-0.00619	+0.15443	85
Significance, P	0.00020***	0.00000***	0.95370	0.14960	
Marital status.					
Correlation between the fraction of single farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	119.93440	257.83206	-0.02186	-0.07963	78
Significance, P	0.00190**	0.00000***	0.85100	0.48680	
Correlation between the fraction of married farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	119.54160	257.83206	+0.05325	+0.10722	78
Significance, P	0.00130**	0.00000***	0.65560	0.35520	
Cultural leaning.					
Correlation between the fraction of culturally liberal farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	564.55951	257.83206	-0.08203	-0.03420	78
Significance, P	0.00000***	0.00000***	0.48330	0.77580	
Correlation between the fraction of culturally moderate farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	557.35616	257.83206	+0.11159	+0.06042	78
Significance, P	0.00000***	0.00000***	0.34520	0.62370	
Correlation between the fraction of culturally conservative farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	146.81568	257.83206	+0.11701	+0.18750	78
Significance, P	0.00450**	0.00000***	0.30940	0.08160	
Farm size.					
Correlation between the fraction of farmers with small farm size (<0.5-0.9) and the fraction of farmers that had a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	192.14818	257.83206	-0.11971	-0.05465	78
Significance, P	0.00000***	0.00000***	0.31280	0.64490	
Correlation between the fraction of farmers with medium farm size (1.0-2.9) and the fraction of farmers that had a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**

	115.69318	257.83206	+0.09457	-0.04383	78
Significance, P	0.00120**	0.00000***	0.42680	0.73380	
Correlation between the fraction of farmers with large farm size (3.0 to >5.0) and the fraction of farmers that had a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	129.06166	257.83206	-0.03560	+0.03980	78
Significance, P	0.00000***	0.00000***	0.76520	0.76550	
Religion.					
Correlation between the fraction of Muslim farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	332.27889	257.83206	+0.02248	+0.06497	78
Significance, P	0.00000***	0.00000***	0.84960	0.61830	
Correlation between the fraction of Christian farmers and the fraction of farmers with a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	342.24317	257.83206	-0.00801	-0.02975	78
Significance, P	0.00000***	0.00000***	0.94420	0.82350	
Effect of prior impression of GM crops on perceptions and acceptance of the technology.					
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having a favourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	157.24070	456.57840	-0.14555	-0.17834	77
Significance, P	0.00000***	0.00000***	0.22260	0.14210	
Correlation between the fraction of farmers having an unfavourable impression of GM crops and the fraction of farmers that perceived farmers in their area as having an unfavourable impression of GM crops.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	152.25590	373.97340	+0.08855	+0.04698	77
Significance, P	0.00020***	0.00000***	0.45230	0.68840	
Correlation between the fraction of farmers having a favourable impression of GM crops and the fraction of farmers that considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	157.24070	365.91494	+0.17473	+0.18094	77
Significance, P	0.00000***	0.00000***	0.14250	0.11200	
Correlation between the fraction of farmers having an unfavourable impression of GM crops the fraction of farmers that did not considered GM crops as a way of increasing quality of life of farmers.					
	Chi(X1)	**Chi(X2)**	**Corr(X1, X2)**	**LCorr(X1, X2)**	**Sample size, N**
	152.25590	245.99190	-0.04014	-0.04805	77
Significance, P	0.00050***	0.00010***	0.79080	0.79030	

[1] Chi(X1) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
[2] Chi(X2) = the chi squared value for the contingency table which tests whether the proportion in coloumn X1 is significantly different among the different groups.
Note: The p-values of Chi(X1) and Chi(X2) are part of the estimation for group equality, i.e. whether the groups share a common probability of success (tested for both the q and p-value).
[3] Corr(X1, X2) = c = the correlation value between column X1 and column X2.

[4] LCorr(X1, X2) = logc = the correlation value between column X1 and column X2 for logit transformed data.
[5] Sample size, N = the number of rows (i.e. number of farmer groups).
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

Appendix E. Results from the Stakeholders survey

E.1. Opinions of various laws, regulations and political measures concerning biotechnology and biosafety in East Africa by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders

Table E.1. Level of support for various laws, regulations and political measures concerning biosafety and biotechnology (A-E)[1] by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[2] divided by perception group (PG)[3] and occupation[4]; in % and [number] of total respondents [78].

	Total	Perception group (PG)	Occupation
A: Support	61.5 % [48]	PG1 ~10% [5], PG2 ~4% [2], PG3 ~27% [13], PG4 ~56% [27], no PG ~2% [1]	Other ~2% [1], famer ~2% [1], agricultural researcher ~31% [15], extension worker ~15% [7], policy maker ~4% [2], civil servant (1) ~29% [14], civil servant (2) ~4% [2], civil servant (3) ~13% [6]
A: Do not support	29.5 % [23]	PG1 ~52% [12], PG2 ~9% [2], PG3 ~17% [4], PG4 ~22% [5],	Other ~4% [1], famer ~9% [2], agricultural researcher ~13% [3], extension worker ~4% [1], civil servant (1) ~26% [6], civil servant (3) ~43% [10]
A: No answer	9.0 % [7]	PG1 ~14% [1], PG3 ~43% [3], PG4 ~43% [3]	Agricultural researcher ~43% [3], extension worker ~43% [3], civil servant (3) ~14% [1]
B: Support	73.1 % [57]	PG1 ~11 % [6], PG2 ~5% [3], PG3 28% [16], PG4 ~54% [31], no PG ~2% [1]	Other ~2% [1], famer ~3% [2], agricultural researcher ~32% [18], extension worker ~17% [10], policy maker ~3% [2], civil servant (1) ~30% [17], civil servant (2) ~3% [2], civil servant (3) ~9% [5]
B: Do not support	20.5 % [16]	PG1 ~69% [11], PG2 ~6% [1], PG3 ~6% [1], PG4 ~19% [3]	Other ~6% [1], famer ~6% [1], civil servant (1) ~19% [3], civil servant (3) ~69% [11]
B: No opinion/do not know	1.3 % [1]	PG1 100% [1]	Civil servant (3) 100% [1]
B: No answer	5.1 % [4]	PG3 75% [3], PG4 25% [1]	Agricultural researcher 75% [3], extension worker 25% [1]
C: Support	75.6 % [59]	PG1 ~5% [3], PG2 ~7% [4], PG3 ~30% [18], PG4 ~56% [33], no PG ~2% [1]	Other ~2% [1], famer ~5% [3], agricultural researcher ~31% [18], extension worker ~15% [9], policy maker ~3% [2], civil

			servant (1) ~31% [18], civil servant (2) ~3% [2], civil servant (3) ~10% [6]
C: Do not support	15.4 % [12]	PG1 100% [12]	Other ~8% [1], agricultural researcher ~8% [1], extension worker ~8% [1], civil servant (1) ~8% [1], civil servant (3) ~67% [8]
C: No opinion/do not know	2.6 % [2]	PG1 100 % [2]	Civil servant (3) 100 % [2]
C: No answer	6.4 % [5]	PG1 20% [1], PG3 40% [2], PG4 40% [2]	Agricultural researcher 40% [2], extension worker 20% [1], civil servant (1) 20% [1], civil servant (3) 20% [1]
D: Support	73.1 % [57]	PG1 ~3% [2], PG2 ~5% [3], PG3 ~32% [18], PG4 ~58% [33], no PG ~2% [1]	Other ~2% [1], famer ~3% [2], agricultural researcher ~33% [19], extension worker ~16% [9], policy maker ~3% [2], civil servant (1) ~32% [18], civil servant (2) ~3% [2], civil servant (3) ~7% [4]
D: Do not support	19.2 % [15]	PG1 ~86% [13], PG2 ~7% [1], PG4 ~7% [1]	Famer ~7% [1], agricultural researcher ~7% [1], extension worker ~7% [1], civil servant (1) ~7% [1], civil servant (3) ~73% [11]
D: No answer	7.7 % [6]	PG1 50% [3], PG2 ~33% [2], PG4 ~17% [1]	Other ~17% [1], agricultural researcher ~17% [1], extension worker ~17% [1], civil servant (1) ~17% [1], civil servant (3) ~33% [2]
E: Strongly disagree	10.5 % [8]	PG1 100 % [8]	Agricultural researcher 12.5% [1], extension worker 12.5% [1], civil servant (3) 75% [6]
E: Somewhat agree	3.8 % [3]	PG2 ~33% [1], PG3 ~33% [1], PG4 ~33% [1]	Agricultural researcher ~33% [1], extension worker ~33% [1], civil servant (2) ~33% [1]
E: Agree	14.1 % [11]	PG1 ~9% [1], PG3 ~55% [6], PG4 ~36% [4]	Agricultural researcher ~18% [2], extension worker ~9% [1], policy maker ~18% [2], civil servant (1) ~45% [5], civil servant (3) ~9% [1]
E: Strongly agree	70.5 % [55]	PG1 ~14% [8], PG2 ~5% [3], PG3 ~24% [13], PG4 ~54% [30], no PG ~2% [1]	Other ~2% [1], famer ~5% [3], agricultural researcher ~31% [17], extension worker ~14% [8],

			civil servant (1) ~27% [15], civil servant (2) ~2% [1], civil servant (3) ~18% [10]
E: No opinion	1.3 % [1]	PG1 100% [1]	Other 100% [1]

[1] A = lifting of the 2012 Kenyan ban on GMO imports; B = the passage of the Ugandan Biotechnology and Biosafety Bill into law; C = the revision of the Tanzanian Biosafety Regulations; D = the amendments to the Ethiopian Biosafety Proclamation; E = regional harmonisation of biosafety and biotechnology laws in East Africa.
[2] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[3] PG = perception group; 1 = negative towards GM crops, 2 = somewhat positive towards GM crops, 3 = positive towards GM crops, 4 = very positive towards GM crops.
[4] Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in the non-governmental organisation sector.
Note: Figures may not add to 100% due to rounding.

E.2. Concerns associated with the adoption of genetically modified (GM) crops as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders

Table E.2.1. Statistical output from the Monte Carlo simulation model for investigating differences in the level of concerns associated with the adoption of genetically modified (GM) crops on the basis of demographic factors among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1].					
Negative health effects (e.g. allerginicity/toxicity)					
	Chi sq.[2]	**Deg.fr.**[3]	**P-value**[4]	**Q-value**[5]	**N**[6]
Age	11.33864	15	0.65220	0.72824	69
Cultural leaning	1.83977	3	0.62430	0.60632	71
Educational level	32.27492	12	0.00120**	0.00125**	70
Family background	3.32386	3	0.35850	0.34434	71
Sex	1.27232	3	0.75390	0.73572	71
Income level	15.49021	15	0.41670	0.41672	65
Knowledge of agriculture and rural life	7.05855	6	0.30220	0.31547	71
Marital status	5.94581	3	0.10930	0.11428	70
Nationality	15.41714	9	0.07650	0.08010	71
Occupation	8.05774	9	0.53750	0.52834	71
Perception group	20.40903	9	0.01450*	0.01555*	70
Upbringing	15.90322	6	0.01270*	0.01428*	71
Negative environmental effects					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	12.92371	15	0.53120	0.60819	75
Cultural leaning	2.55855	3	0.48290	0.46480	77
Educational level	30.15870	12	0.00250**	0.00264**	76
Family background	1.56350	3	0.68900	0.66769	77
Sex	3.52893	3	0.32750	0.31703	77
Income level	13.78978	15	0.55540	0.54153	71
Knowledge of agriculture and rural life	4.61311	6	0.62270	0.59430	77
Marital status	1.81144	3	0.63820	0.61245	76
Nationality	9.84533	9	0.36370	0.36315	77
Occupation	30.35296	21	0.05480	0.08512	77
Perception group	29.16621	9	0.00100***	0.00061***	76
Upbringing	4.30831	6	0.65460	0.63503	77
Development of resistance by pests and pathogens, including "superweeds"					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	20.80879	15	0.09550	0.14305	75
Cultural leaning	2.29939	3	0.52330	0.51264	77
Educational level	38.63892	12	0.00010***	0.00012***	76
Family background	4.37098	3	0.22720	0.22409	77
Sex	0.63120	3	0.89890	0.88925	77
Income level	11.94872	15	0.71020	0.68291	71
Knowledge of agriculture and rural life	11.94872	15	0.70800	0.68291	77
Marital status	4.87235	6	0.57570	0.56029	76

Nationality	8.77129	9	0.47030	0.45865	77
Occupation	29.22432	21	0.07090	0.10872	77
Perception group	40.57016	9	0.00000***	0.00001***	76
Upbringing	6.02429	6	0.43800	0.42047	77
Religious/cultural concerns					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	17.67023	15	0.21010	0.28040	69
Cultural leaning	5.17058	3	0.16380	0.15972	71
Educational level	22.28526	12	0.03090*	0.03444*	70
Family background	3.22238	3	0.36530	0.35859	71
Sex	2.61053	3	0.47360	0.45565	71
Income level	13.19422	15	0.61110	0.58730	65
Knowledge of agriculture and rural life	2.55606	6	0.87690	0.86214	71
Marital status	3.89526	3	0.26920	0.27300	70
Nationality	12.35348	9	0.18820	0.19411	71
Occupation	22.56645	21	0.23150	0.36752	71
Perception group	17.67842	9	0.03390*	0.03909*	70
Upbringing	6.39057	6	0.39430	0.38089	71
Damage relationships with neighbouring countries that oppose commercialisation of GM crops					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	10.49707	15	0.74820	0.78736	71
Cultural leaning	2.16599	3	0.54800	0.53868	73
Educational level	28.56159	12	0.00390**	0.00457**	72
Family background	5.52434	3	0.13350	0.13719	73
Sex	2.66252	3	0.46790	0.44663	73
Income level	23.77720	15	0.05890	0.06897	67
Knowledge of agriculture and rural life	5.80976	6	0.44690	0.44483	73
Marital status	2.89530	3	0.42360	0.40805	72
Nationality	13.94561	9	0.12080	0.12427	73
Occupation	42.26405	21	0.00110**	0.00390**	73
Perception group	33.74094	9	0.00000***	0.00010***	72
Upbringing	11.17900	6	0.08070	0.08300	73
Damage relationship & loss of trade with E.U. which is not in favour of GMOs					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	18.03950	15	0.19000	0.26059	72
Cultural leaning	5.79352	3	0.12340	0.12210	74
Educational level	10.63452	12	0.59270	0.56047	73
Family background	4.25974	3	0.24140	0.23475	74
Sex	2.91981	3	0.42040	0.40415	74
Income level	23.78470	15	0.05410	0.06884	68
Knowledge of agriculture and rural life	5.22042	6	0.53380	0.51587	74
Marital status	0.21553	3	0.97880	0.97504	73
Nationality	6.71265	9	0.69360	0.66701	74
Occupation	20.76599	21	0.39280	0.47331	74
Perception group	24.21829	9	0.00320**	0.00397**	73

Upbringing	2.46959	6	0.88390	0.87185	74
Socio-economic reasons					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	12.30039	15	0.57760	0.65616	71
Cultural leaning	0.25062	3	0.96903	0.97260	73
Educational level	14.33119	12	0.27310	0.28006	72
Family background	2.22244	3	0.55430	0.52754	73
Sex	3.62122	3	0.31950	0.30538	73
Income level	23.40032	15	0.06740	0.07600	67
Knowledge of agriculture and rural life	3.40342	6	0.79230	0.75677	73
Marital status	0.87843	3	0.84740	0.83063	72
Nationality	4.40113	9	0.90830	0.88309	73
Occupation	30.14047	21	0.01440*	0.08920	73
Perception group	28.78580	9	0.00010***	0.00070**	72
Upbringing	6.83756	6	0.34410	0.33613	73
Altered social structure					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	9.05533	15	0.81820	0.87461	74
Cultural leaning	2.24159	3	0.55460	0.52380	76
Educational level	14.89314	12	0.23990	0.24733	75
Family background	0.95229	3	0.83210	0.81279	76
Sex	8.27020	3	0.03690*	0.04075	76
Income level	24.10693	15	0.06100	0.06330	70
Knowledge of agriculture and rural life	5.29500	6	0.50810	0.50657	76
Marital status	4.83471	3	0.17710	0.18431	75
Nationality	8.05774	9	0.53720	0.52834	76
Occupation	31.57879	21	0.04990*	0.06455	76
Perception group	26.29425	9	0.00260**	0.00183**	75
Upbringing	2.75390	6	0.86160	0.83904	76

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

Table E.2.2. Level of concerns associated with potential negative effects (A-H)[1] that might arise as a result of the adoption of genetically modified (GM) crops, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[2] divided by perception group (PG)[3], occupation[4] and educational level; in % and [number] of total respondents [78].					
	Total	**Perception group (PG)**	**Occupation**	**Educational level**	**Nationality**
A: Not concerned	32.1 % [25]	PG1 4% [1], PG3 20% [5], PG4 76% [19]	Farmer 8% [2], agricultural researcher 44% [11], extension worker 16% [4], civil servant (1) 24% [6], civil servant (3) 8% [2]	Secondary 12% [3], some college 8% [2], Bachelor 16% [4], Master 20% [5], PhD 40% [10], no specified education 4% [1]	Kenya 68% [17], Uganda 12% [3], Ethiopia 20% [5]
A: Somewhat concerned	10.3 % [8]	PG1 12.5% [1], PG3 50% [4], PG3 37.5% [3]	Other 12.5% [1], agricultural researcher 50 % [4], extension worker [1], civil servant (1) 12.5% [1], civil servant (3) 12.5% [1]	Bachelor 25% [2], Master 50% [4], PhD 25% [2]	Kenya 25% [2], Uganda 12.5% [1], Tanzania 25% [2], Ethiopia 37.5% [3]
A: Concerned	17.9 % [14]	PG1 ~21% [3], PG2 ~ 7% [1], PG3 ~ 36% [5], PG4 ~ 36% [5]	Agricultural researcher ~21% [3], policymaker ~14% [2], civil servant (1) ~36% [5], civil servant (3) ~29% [4]	Secondary ~7% [1], Bachelor ~14% [2], Master ~64% [9], PhD ~14% [2]	Kenya [10], Uganda [2], Tanzania [2]
A: Very concerned	32.1 % [25]	PG1 36% [9], PG2 12% [3], PG3 20% [5], PG4 28% [7], no PG 4% [1]	Other 4% [1], farmer 4% [1], agricultural researcher 12% [3], extension worker 20% [5], civil servant (1) 28% [7], civil servant (2) 4% [1], civil servant (3) 28% [7]	Some college 20% [5], Bachelor 52% [13], Master 28% [7]	Kenya 64% [16], Uganda 16% [4], Tanzania 16% [4], Ethiopia 4% [1]
A: No opinion/answer	7.7 % [6]	PG1 ~67% [4], PG3 ~17% [1], PG4 ~17% [1]	Extension worker ~17% [1], civil servant (1) ~ 17% [1], civil servant (2) ~ 17% [1], civil servant (3) 50% [3]	Some college~33% [2], Bachelor 50% [3], Master ~17% [1]	Kenya ~67% [4], Uganda ~17% [1], Tanzania ~17% [1]
B: Not concerned	24.2 % [19]	PG1 ~5% [1], PG3 ~16% [3], PG4 ~79% [15]	Other ~5% [1], farmer ~11% [2], agricultural researcher ~ 26% [5], extension worker ~21% [4], civil servant (1) ~26% [5], civil servant (3) ~11% [2]	Secondary ~16% [3], some college ~11% [2], Bachelor ~26% [5], Master ~16% [3], PhD ~26% [5], no specified education ~5% [1]	Kenya ~68% [13], Uganda ~21% [4], Ethiopia ~11% [2]
B: Somewhat	12.8 %	PG3 30% [3],	Agricultural	Some college 10%	Kenya 60%

concerned	[10]	PG4 70% [7]	researcher 70% [7], extension worker 10% [1], civil servant (1) 20% [2]	[1], Master 40% [4], PhD 50% [5]	[6], Tanzania 10% [1], Ethiopia 30% [3]
B: Concerned	29.5 % [23]	PG1 ~22% [5], PG2 ~9% [2], PG3 ~43% [10], PG4 ~26% [6]	Agricultural researcher ~26% [6], extension worker ~9% [2], policymaker ~9% [2], civil servant (1) ~30% [7], civil servant (3) ~26% [6]	Secondary ~4%[1], Bachelor ~30%[7], Master ~48% [11], PhD ~17% [4]	Kenya ~57% [13], Uganda ~13% [3], Tanzania ~17% [4], Ethiopia ~13% [3]
B: Very concerned	32.1 % [25]	PG1 48% [12], PG2 8% [2], PG3 16% [4], PG4 24% [6], no PG 4% [1]	Other 4% [1], farmer 4% [1],agricultural researcher 12% [3], extension worker 16% [4], civil servant (1) 20% [5], civil servant (2) 8% [2], civil servant (3) 36% [9]	Some college 20% [5], Bachelor 48% [12], Master 32% [8]	Kenya 64% [16], Uganda 16% [4], Tanzania 16% [4], Ethiopia 4% [1]
B: No answer	1.3 % [1]	PG4 100% [1]	Civil servant (1) 100% [1]	Some college 100% [1]	Kenya 100% [1]
C: Not concerned	20.5 % [16]	PG3 25% [4], PG4 75% [12]	Farmer ~13% [2], agricultural researcher ~31% [5], extension worker ~19% [3], civil servant (1) ~31% [5], civil servant (3) ~6% [1]	Secondary ~19% [3], some college ~13% [2], Bachelor 25% [4], Master ~6% [1], PhD ~31% [5], no specified education ~6% [1]	Kenya ~63% [10], Uganda ~19% [3], Tanzania ~6% [1], Ethiopia ~13% [2]
C: Somewhat concerned	16.7 % [13]	PG2 ~8% [1], PG3 ~23% [3], PG4 ~69% [9]	Other ~ 8% [1], farmer ~8% [1], agricultural researcher ~ 54% [7], extension worker ~8% [1], civil servant (1) ~15% [2], civil servant (3) ~8% [1]	Some college ~15% [2], Bachelor ~15% [2], Master ~38% [5], PhD ~31% [4]	Kenya ~77% [10], Uganda ~8% [1], Ethiopia ~15% [2]
C: Concerned	23.1 % [18]	PG1 ~6%[1], PG2 ~11% [2], PG3 ~50% [9], PG4 ~33% [6]	Agricultural researcher ~33% [6], extension worker ~11% [2], policymaker ~6% [1], civil servant (1) ~33% [6], civil servant (3) ~17% [3]	Secondary ~6% [1], Bachelor ~6% [1], Master ~61% [11], PhD ~28% [5]	Kenya ~44% [8], Uganda ~17% [3], Tanzania ~17% [3], Ethiopia ~22% [4]
C: Very concerned	38.5 % [30]	PG1 ~57% [17], PG2	Other ~3% [1], agricultural	Some college ~13% [4],	Kenya ~67% [20], Uganda

		~3% [1], PG3 ~13%[4], PG4 23% [7], no PG ~3% [1]	researcher 10% [3], extension worker ~17% [5], policymaker ~3% [1], civil servant (1) 20% [6], civil servant (2) ~7%[2], civil servant (3) 40% [12]	Bachelor ~57% [17], Master 30% [9]	~13% [4], Tanzania ~17% [5], Ethiopia ~3% [1]
C: No answer	1.3 % [1]	PG4 100 %[1]	Civil servant (1) 100% [1]	Some college 100% [1]	Kenya 100% [1]
D: Not concerned	41.0 % [32]	PG1 ~6% [2], PG2 ~3% [1], PG3 25% [8], PG4 ~66% [21]	Farmer ~6% [2], agricultural researcher ~38% [12], extension worker ~19% [6], civil servant (1) ~22% [7], civil servant (2) ~3% [1], civil servant (3) ~13% [4]	Secondary ~6% [2], some college ~9% [3], Bachelor ~28% [9], Master ~ 28% [9], PhD 25% [8], no specified education ~3% [1]	Kenya ~63% [20], Uganda ~13% [4], Tanzania ~9% [3], Ethiopia ~16% [5]
D: Somewhat concerned	20.5 % [16]	PG1 ~13% [2], PG2 ~6%[1], PG3 ~38% [6], ~44% PG4 [7]	Other ~6% [1], agricultural researcher 25% [4], extension worker ~6% [1], policymaker ~13% [2], civil servant (1) ~38% [6], civil servant (3) ~13% [2]	Secondary ~6% [1], Bachelor ~19% [3], Master ~56% [9], PhD ~19% [3]	Kenya ~63% [10], Uganda 25% [4], Ethiopia ~13% [2]
D: Concerned	12.8 % [10]	PG1 30% [3], PG2 10% [1], PG3 40% [4], PG4 20% [2]	Agricultural researcher 30% [3], extension worker 10% [1], civil servant (1) 30% [3], civil servant (3) 40% [4]	Secondary 10% [1], Bachelor 30% [3], Master 50% [5], PhD 10% [1]	Kenya 50% [5], Uganda 10% [1], Tanzania 40% [4]
D: Very concerned	16.7 % [13]	PG1 ~46% [6], PG2 ~8% [1], PG3 ~15% [2], PG4 ~23% [3], no PG ~8% [1]	Farmer ~8% [1], agricultural researcher ~15% [2], extension worker ~23% [3], civil servant (1) ~15%[2], civil servant (3) ~38% [5]	Some college ~38% [5], Bachelor ~46% [6], Master ~8% [1], PhD ~8% [1]	Kenya ~69% [9], Uganda ~8% [1], Tanzania ~15% [2], Ethiopia ~8% [1]
D: No opinion/no answer	9.0 % [7]	PG1 ~71% [5], PG4 ~29% [2]	Other ~14% [1], civil servant (1) ~29% [2], civil servant (2) ~14% [1], civil servant (3) ~43% [3]	Some college ~14% [1], Bachelor ~43% [3], Master ~29% [2], PhD ~14% [1]	Kenya ~71% [5], Uganda ~14% [1], Ethiopia ~14% [1]
E: Not	35.9 %	PG1 ~4%[1],	Other ~4% [1],	Secondary ~7%	Kenya ~46%

concerned	[28]	PG2 ~7% [2], PG3 25% [7], PG4 ~64%[18]	farmer ~7% [2], agricultural researcher 50% [14], extension worker ~7% [2], civil servant (1) ~21% [6], civil servant (2) ~4% [1], civil servant (3) ~7%[2]	[2], some college ~4% [1], Bachelor ~21% [6], Master ~18% [5], PhD ~46% [13], no specified education ~4% [1]	[13], Uganda ~18% [5], Tanzania ~11% [3], Ethiopia 25% [7]
E: Somewhat concerned	17.9 % [14]	PG1 ~7% [1], PG2 ~14% [2], PG3 ~57% [8], PG4 ~21% [3]	Farmer ~7% [1], agricultural researcher ~21% [3], extension worker ~14% [2], civil servant (1) 50% [7], civil servant (3) ~7% [1]	Secondary ~7% [1], some college ~14% [2], Bachelor ~29% [4], Master 50% [7]	Kenya ~71% [10], Tanzania ~14% [2], Ethiopia ~14% [2]
E: Concerned	23.1 [18]	PG1 ~22% [4], PG3 ~22% [4], PG4 ~56% [10]	Agricultural researcher ~6% [1], extension worker ~33%[6], policymakers ~11% [2], civil servant (1) ~28% [5], civil servant (3) ~22% [4]	Secondary ~6% [1], some college ~11% [2], Bachelor ~28% [5], Master 50% [9], PhD ~6% [1]	Kenya ~78% [14], Uganda ~17% [3], Tanzania ~6% [1]
E: Very concerned	16.7 % [13]	PG1 ~62% [8], PG2 ~8% [1], PG4 ~23% [3], no PG ~8% [1]	Other ~8% [1], agricultural researcher ~23% [3], extension worker ~8% [1], civil servant (1) ~8% [1], civil servant (3) ~54% [7]	Some college ~23% [3], Bachelor ~46% [6], Master ~31% [4]	Kenya ~62% [8], Uganda ~15% [2], Tanzania ~23% [3]
E: No opinion/no answer	6.4 % [5]	PG1 80% [4], PG4 20% [1]	Civil servant (1) 20% [1], civil servant (2) 20% [1], civil servant (3) 60% [3]	Some college 20% [1], Bachelor 60% [3], Master 20% [1]	Kenya 80% [4], Uganda 20% [1]
F: Not concerned	21.8 % [17]	PG1 ~6% [1], PG3 ~29% [5], PG4 ~65% [11]	Other ~6% [1], farmer ~6% [1], agricultural researcher ~35% [6], extension worker ~6% [1], civil servant (1) ~35% [6], civil servant (3) ~12% [2]	Secondary ~6% [1], Bachelor ~29% [5], Master ~24% [4], PhD ~35% [6], no specified education ~6% [1]	Kenya ~47% [8], Uganda ~29% [5], Tanzania ~12% [2], Ethiopia ~12% [2]
F: Somewhat concerned	17.9 % [14]	PG1 ~14% [2], PG2 ~21% [3], PG3 ~29% [4], PG4	Farmer ~7%[1], agricultural researcher ~36% [5], civil servant (1) ~36% [5], civil servant (2)	Secondary ~7% [1], some college ~7% [1], Bachelor ~14% [2], Master 50% [7], PhD	Kenya ~57% [8], Uganda ~7% [1], Tanzania ~14% [2],

		~36% [5]	~7%[1], civil servant (3) ~14%[2]	~21% [3]	Ethiopia ~21% [3]
F: Concerned	24.4 % [19]	PG1 ~16% [3], PG3 ~42% [8], PG4 ~42% [8]	Agricultural researcher ~16% [3], extension worker ~26% [5], policymaker ~5% [1], civil servant (1) ~26% [5], civil servant (2) ~5% [1], civil servant (3) ~21% [4]	Secondary ~5% [1], some college ~16% [3], Bachelor ~32% [6], Master ~37% [7], PhD ~11% [2]	Kenya ~68% [13], Uganda ~11% [2], Tanzania ~11% [2], Ethiopia ~11% [2]
F: Very concerned	30.8 % [24]	PG1 ~46% [11], PG2~4% [1], PG3 ~8% [2], PG4 ~38% [9], no PG ~4%[1]	Other ~4% [1], agricultural researcher ~29% [7], extension worker ~17% [4], policymaker ~4% [1], civil servant (1) ~13% [3], civil servant (3) ~33% [8]	Secondary ~4% [1], some college ~13% [3], Bachelor ~42% [10], Master ~29% [7], PhD ~13% [3]	Kenya ~71% [17], Uganda ~8% [2], Tanzania ~13% [3], Ethiopia ~8% [2]
F: No opinion/no answer	5.2 % [4]	PG1 25% [1], PG3 25% [1], PG4 50% [2]	Farmer 25% [1], extension worker 25% [1], civil servant (1) 25% [1], civil servant (3) 25% [1]	Some college 50% [2], Bachelor 25% [1], Master 25% [1]	Kenya 75% [3], Uganda 25% [1]
G: Not concerned	30.8 % [24]	PG1 ~4% [1], PG2 ~4% [1], PG3 ~17% [4], PG4 75% [18]	Other ~4% [1], farmer ~13% [3], agricultural researcher ~38% [9], extension worker ~17% [4], civil servant (1) 25% [6], civil servant (3) ~4% [1]	Secondary ~8% [2], some college ~17% [4], Bachelor 25% [6], Master ~17% [4], PhD 29% [7], no specified education ~4% [1]	Kenya ~63% [15], Uganda ~17% [4], Tanzania ~8% [2], Ethiopia ~13% [3]
G: Somewhat concerned	20.5 % [16]	PG1 ~6% [1], PG3 ~38% [6], PG4 ~56% [9]	Agricultural researcher ~44% [7], extension worker ~19% [3], policymaker ~6% [1], civil servant (1) ~13% [2], civil servant (3) ~19% [3]	Secondary ~6% [1], Bachelor 25% [4], Master ~44% [7], PhD 25% [4]	Kenya ~63% [10], Uganda ~13% [2], Tanzania ~6% [1], Ethiopia ~19% [3]
G: Concerned	20.5 % [16]	PG1 ~31% [5], PG2 ~6% [1], PG3 ~44% [7], PG4 ~19% [3]	Agricultural researcher ~13% [2], policymaker ~6% [1], civil servant (1) ~ 44% [7], civil servant (3) ~38% [6]	Secondary ~6% [1], some college ~6% [1], Bachelor 25% [4], Master 50% [8], PhD ~13% [2]	Kenya ~69% [11], Uganda ~6% [1], Tanzania ~13% [2], Ethiopia ~13% [2]

G: Very concerned	21.8 % [17]	PG1 ~53% [9], PG2 ~6% [1], PG3 ~18% [3], PG4 ~18%[3], no ~6% PG [1]	Agricultural researcher ~12% [2], extension worker ~24% [4], civil servant (1) ~24%[4], civil servant (3) ~41% [7]	Some college ~18% [3], Bachelor ~47% [8], Master ~29% [5], PhD ~6% [1]	Kenya ~53% [9], Uganda ~24% [4], Tanzania ~18% [3], Ethiopia ~6% [1]
G: No opinion/no answer	6.4 % [5]	PG1 40% [2], PG2 20% [1], PG4 40% [2]	Other 20%[1], agriculture researcher 20% [1], civil servant (1) 20% [1], civil servant (2) 40% [2]	Some college 20% [1], Bachelor 40% [2], Master 40% [2]	Kenya 80% [4], Tanzania 20% [1]
H: Not concerned	55.1 % [43]	PG1 ~9% [4], PG2 ~7% [3], PG3 ~28% [12], PG ~56% [24]	Other ~5%[2], farmer ~7% [3], agricultural researcher ~30% [13], extension worker ~14% [6], policymaker ~2% [1], civil servant (1) ~33% [14], civil servant (2) ~2% [1], civil servant (3) ~7% [3]	Secondary ~9% [4], some college ~9% [4], Bachelor ~23% [10], Master ~30% [13], PhD ~26% [11], no specified education ~2% [1]	Kenya ~58% [25], Uganda ~16% [7], Tanzania ~9% [4], Ethiopia ~16% [7]
H: Somewhat concerned	16.7 % [13]	PG1 ~15% [2], PG2 ~8% [1], PG3 ~31% [4], PG4 ~46% [6]	Agricultural researcher ~38% [5], extension worker ~15% [2], policymaker ~8% [1], civil servant (1) ~15% [2], civil servant (3) ~23% [3]	Bachelor ~38% [5], Master ~46% [6], PhD ~15% [2]	Kenya ~85% [11], Tanzania ~8% [1], Ethiopia ~8% [1]
H: Concerned	14.1 % [11]	PG1 ~54% [6], PG3 ~36% [4], PG4 ~9%[1]	Agricultural researcher ~9% [1], civil servant (1) ~27% [3], civil servant (3) ~64% [7]	Some college ~9% [1], Bachelor ~45% [5], Master ~36% [4], PhD ~9% [1]	Kenya ~64% [7], Uganda ~27% [3], Tanzania ~9% [1]
H: Very concerned	11.5% [9]	PG1 67% [6], PG4 ~22% [2], no PG ~11% [1]	Agricultural researcher ~22% [2], extension worker ~22% [2], civil servant (2) ~11% [1], civil servant (3) ~44% [4]	Some college ~33% [3], Bachelor ~33% [3], ~33% Master [3]	Kenya ~55% [5], Uganda ~11% [1], Tanzania ~22% [2], Ethiopia ~11% [1]
H: No opinion/no answer	2.6 % [2]	PG4 100% [2]	Extension worker 50% [1], civil servant (1) 50% [1]	Some college 50% [1], Bachelor 50% [1]	Kenya 50% [1], Tanzania 50% [1]

[1] A = negative health effects; B = negative environmental effects; C = development of resistance by

pest and pathogens; D = religious/cultural concerns; E = damage relationships with neighbouring countries that oppose GM crop commercialisation; F = damage relationships and loss of trade with EU; G = socio-economic reasons; H = altered social structure.
[2] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[3] PG = perception group; 1 = negative towards GM crops, 2 = somewhat positive towards GM crops, 3 = positive towards GM crops, 4 = very positive towards GM crops.
[4] Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in the non-governmental organisation sector.
Note: Figures may not add to 100% due to rounding.

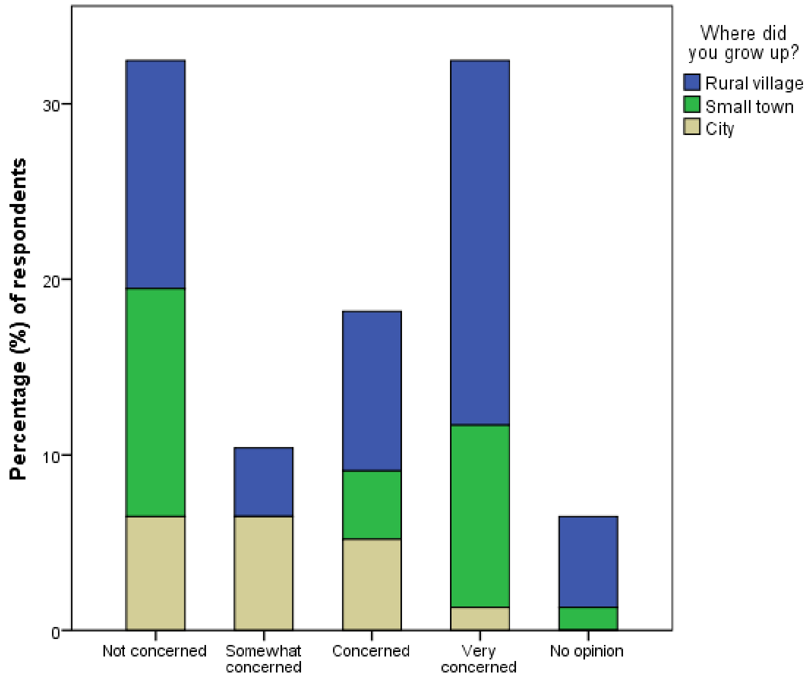


Figure E.2.1. Level of concern associated with negative health effects of genetically modified (GM) crops as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by upbringing (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the level of concern about potential negative health effects on the basis of upbringing ($p<0.05$). Response rate: ~99% (77 out of 78 participants).

Note: Numbers in brackets represents frequency of respondents. Figures may not add to 100% due to rounding. **Not concerned [25]:** Rural village 40% [10], small town 40% [10], city 20% [5]. **Somewhat concerned [8]:** Rural village 37.5% [3], city 62.5% [5]. **Concerned [14]:** Rural village 50% [7], small town ~21% [3], city ~29% [4]. **Very concerned [25]:** Rural village 64% [16], small town 32% [8], city 4% [1]. **No opinion [5]:** Rural village 80% [4], small town 20% [1]. **No answer [1]:** Small town 100% [1] (not shown in Fig. E.2.1).

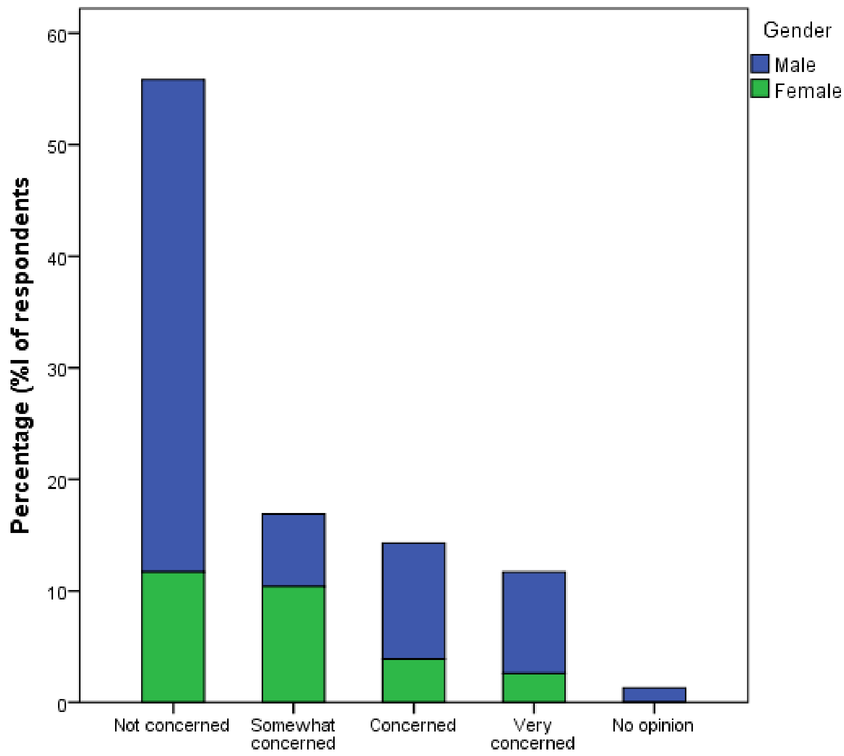


Figure E.2.2. Level of concern associated with altered social structure as a result of the adoption of genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by sex (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the level of concern about altered social structure on the basis of sex ($p<0.05$). Response rate: ~99% (77 out of 78 participants).

Note: Numbers in brackets represents frequency of respondents. Figures may not add to 100% due to rounding. **Not concerned [43]:** Male~79% [34], female ~21% [9]. **Somewhat concerned [13]:** Male ~38% [5], female ~62% [8]. **Concerned [11]:** Male ~73% [8], female ~27% [3]. **Very concerned [9]:** Male ~79% [7], female ~21% [2]. **No opinion [1]:** Male 100% [1]. **No answer [1]:** Female 100% [1] (not shown in Fig. E.2.2).

E.3. Likelihood of socio-economic possible changes as a result of genetically modified (GM) crop adoption in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders

Table E.3.1. Statistical output from the Monte Carlo simulation model for investigating differences in perceived likelihood of possible socio-economic changes associated with the adoption of genetically modified (GM) on the basis of demographic factors among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1].					
Socio-economic change: Local smallholder Farmers' Rights are negatively affected.					
	Chi sq.[2]	**Deg.fr.[3]**	**P-value[4]**	**Q-value[5]**	**N[6]**
Age	14.18645	15	0.43640	0.51144	73
Cultural leaning	2.15124	3	0.55890	0.54162	75
Educational level	24.43275	12	0.01540*	0.01775*	74
Family background	2.04862	3	0.57700	0.56238	75
Sex	1.74042	3	0.64790	0.62799	75
Income level	18.27870	15	0.23690	0.24830	69
Knowledge of agriculture and rural life	8.44631	6	0.20840	0.20719	75
Marital status	2.64531	3	0.47110	0.44960	74
Nationality	9.74513	9	0.37310	0.37151	75
Occupation	32.14165	21	0.03270*	0.05664	75
Perception group	56.64659	9	0.00000***	0.00000***	74
Upbringing	4.92913	6	0.57740	0.55293	75
Socio-economic change: Women are negatively affected (gender inequality).					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	12.68839	15	0.51890	0.62635	72
Cultural leaning	0.98549	3	0.82890	0.80476	74
Educational level	12.03310	12	0.45050	0.44303	73
Family background	3.22679	3	0.35890	0.35796	74
Sex	4.89130	3	0.17870	0.17993	74
Income level	13.90954	15	0.53620	0.53240	68
Knowledge of agriculture and rural life	4.28742	6	0.64740	0.63784	74
Marital status	3.49168	3	0.29260	0.32184	73
Nationality	17.55808	9	0.04740*	0.04066*	74
Occupation	45.86095	21	0.00390**	0.00133**	74
Perception group	44.23792	9	0.00000***	0.00000***	73
Upbringing	5.91612	6	0.44330	0.43265	74
Socio-economic change: Concentration of power and capital in commercial farms.					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	10.69236	15	0.72990	0.77408	74
Cultural leaning	5.84100	3	0.12020	0.11961	76
Educational level	15.76779	12	0.19430	0.20210	74
Family background	1.77153	3	0.63950	0.62115	76
Sex	1.77153	3	0.63590	0.62115	76
Income level	10.53310	15	0.81620	0.78494	70
Knowledge of agriculture and rural life	9.18552	6	0.16010	0.16341	76

Marital status	0.72501	3	0.87970	0.86731	75
Nationality	12.64076	9	0.17060	0.17955	76
Occupation	29.74302	21	0.04550*	0.09727	76
Perception group	37.37626	9	0.00000***	0.00002**	75
Upbringing	7.75146	6	0.25930	0.25688	76
Socio-economic change: Increased income gap between the rich and the poor farmers.					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	12.73944	15	0.54280	0.62242	74
Cultural leaning	1.77181	3	0.63870	0.62109	76
Educational level	12.80032	12	0.39840	0.38372	75
Family background	3.12941	3	0.38450	0.37210	76
Sex	6.32776	3	0.09600	0.09671	76
Income level	16.28591	15	0.35800	0.36331	70
Knowledge of agriculture and rural life	7.39886	6	0.28200	0.28553	76
Marital status	4.21912	3	0.23630	0.23875	75
Nationality	3.03517	9	0.97380	0.96288	76
Occupation	26.77619	21	0.10380	0.17838	76
Perception group	30.74946	9	0.00010**	0.00033**	75
Upbringing	2.17511	6	0.91350	0.90291	76

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.

Table E.3.2. Likelihood of possible socio-economic changes (A-D)[1] associated with the adoption of genetically modified (GM) crops in East Africa, as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[2] divided by perception group (PG)[3] and occupation[4]; in % and [number] of total respondents [78].			
	Total	**Perception group (PG)**	**Occupation**
A: Not likely	38.5 % [30]	PG3 ~23% [7], PG4 ~73% [22], no PG~3% [1]	Farmer ~7% [2], agricultural researcher ~43% [13], extension worker 10% [3], policy maker ~3% [1], civil servant (1) 30% [9], civil servant (3) ~7% [2]
A: Somewhat likely	16.7 % [13]	PG1 ~15% [2], PG3 ~31% [4], PG4 ~54% [7]	Other ~8% [1], agricultural researcher 23% [3], extension worker ~15% [2], civil servant (1) ~38% [5], civil servant (3) ~15% [2]
A: Likely	15.4 % [12]	PG1 ~8% [1], PG2 25% [3], PG3 ~42% [5], PG4 25% [3]	Agricultural researcher ~17% [2], extension worker ~17% [2], policy maker ~8% [1], civil servant (1) ~33% [4], civil servant (2) ~8% [1], civil servant (3) ~17% [2]
A: Very likely	25.6 % [20]	PG1 75% [15], PG2 5% [1], PG3 10% [2], PG4 10% [2]	Other 5% [1], farmer 5% [1], agricultural researcher 10% [2], extension worker 10% [2], civil servant (1) 10% [2], civil servant (2) 5% [1], civil servant (3) 55% [11]
A: No answer	3.8 [3]	PG3 ~67% [2], PG4 ~33% [1]	Agricultural researcher ~33% [1], extension worker ~67% [2]
B: Not likely	60.3 % [47]	PG1 ~4% [2], PG2 ~4% [2], PG3 ~30% [14], PG4~60% [28], no PG~2% [1]	Other ~2% [1], farmer ~4% [2], agricultural researcher ~38% [18], extension worker ~13% [6], policy maker ~4% [2], civil servant (1) ~32% [15], civil servant (3) ~6% [3]
B: Somewhat likely	14.1 % [11]	PG1 ~18% [2], PG2 ~18% [2], PG3~27% [3], PG4 ~36% [4]	Farmer ~9% [1], civil servant (1) ~45% [5], civil servant (2) ~9% [1], civil servant (3) ~36% [4]
B: Likely	9.0 % [7]	PG1 ~86% [6], PG4 ~14% [1]	Agricultural researcher ~14% [1], civil servant (3) ~86% [6]
B: Very likely	11.5 [9]	PG1 ~78% [7], PG4~22% [2]	Other ~11% [1], agricultural researcher ~22 % [2], extension worker ~11% [1], civil servant (2) ~11% [1], civil servant (3) ~44% [4]
B: Do not know/no answer	4.9 % [4]	PG1 25% [1], PG3 75% [3]	Agricultural researcher 25% [1], extension worker 75% [3]

C: Not likely	30.8 % [24]	PG1 ~4% [1], PG3 ~25% [6], PG4 ~67% [16], no PG ~4% [1]	Farmer ~8% [2], agricultural researcher ~42% [10], extension worker ~4% [1], civil servant (1) ~38% [9], civil servant (3) ~8% [2]
C: Somewhat likely	15.4 % [12]	PG1 ~8% [1], PG2 25% [3], PG3 ~67% [8]	Other ~8% [1], agricultural researcher 25% [3], extension worker ~33% [4], policy maker ~8% [1], civil servant (1) ~17% [2], civil servant (3) ~8% [1]
C: Likely	23.1 % [18]	PG1 ~11% [2], PG2 ~11% [2], PG3 ~44% [8], PG4 ~33% [6]	Farmer ~5% [1], agricultural researcher ~17% [3], extension worker ~17% [3], civil servant (1) ~28% [5], civil servant (2) ~5% [1], civil servant (3) ~28% [5]
C: Very likely	28.2 % [22]	PG1 ~64% [14], PG2 ~9% [2], PG3 ~9% [2], PG4 ~18% [4]	Other ~5% [1], agricultural researcher ~18% [4], extension worker ~14% [3], civil servant (1) ~18% [4], civil servant (2) ~5% [1], civil servant (3) ~41% [9]
C: Do not know/no answer	2.6 % [2]	PG3 50% [1], PG4 50% [1]	Agricultural researcher 50% [1], policy maker 50% [1]
D: Not likely	37.2 % [29]	PG3 ~24% [7], PG4 ~72% [21], no PG ~3% [1]	Farmer ~7% [2], agricultural researcher ~38% [11], extension worker ~17% [5], policy maker ~3% [1], civil servant (1) ~31% [9], civil servant (3) ~3% [1]
D: Somewhat likely	20.5 % [16]	PG1 ~19% [3], PG2 12.5% [2], PG3 ~31% [5], PG4 37.5% [6]	Other ~6% [1], farmer ~6% [1], agricultural researcher ~19% [3], extension worker ~19% [3], civil servant (1) ~31% [5], civil servant (2) ~6% [1], civil servant (3) ~13% [2]
D: Likely	14.1 % [11]	PG1 ~36% [4], PG3 ~36% [4], PG4~27% [3]	Agricultural researcher ~18% [2], extension worker ~18% [2], civil servant (1) ~18% [2], civil servant (3) 45% [5]
D: Very likely	25.6 % [20]	PG1 55% [11], PG2 10% [2], PG3 10% [2], PG4 25% [5]	Other 5% [1], agricultural researcher 5% [5], extension worker 5% [1], civil servant (1) 15% [3], civil servant (2) 5% [1], civil servant (3) 45% [9]
D: Do not know/no answer	2.6 % [2]	PG3 100% [2]	Policymaker 50% [1], civil servant (2) 50% [1]

[1] A = local smallholder farmers' rights are negatively affected; B = women are negatively affected; C = increased income gap between rich and poor farmers; D = concentration of power and capital in commercial farms.
[2] Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[3] PG = perception group; 1 = negative towards GM crops, 2 = somewhat positive towards GM crops, 3 =

positive towards GM crops, 4 = very positive towards GM crops.
[4] Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in the non-governmental organisation sector.
Note: Figures may not add to 100% due to rounding.

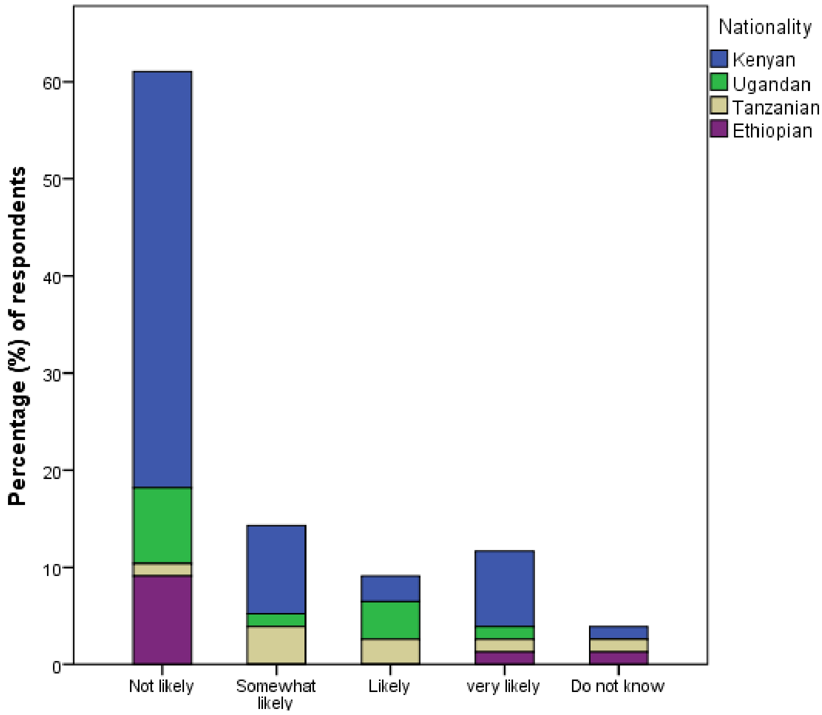


Figure E.3.1. Likelihood of women becoming negatively affected (i.e. gender inequality) due to adoption of genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the perceived likelihood of women becoming negatively affected on the basis of nationality ($p<0.05$). Response rate: ~99% (77 out of 78 participants).

Note: Numbers in brackets represents frequency of respondents. Figures may not add to 100% due to rounding. **Not likely [47]:** Kenyan ~70% [33], Uganda ~13% [6], Tanzania ~2% [1], Ethiopia ~15% [7]. **Somewhat likely [11]:** Kenyan ~64% [7], Ugandan ~9% [1], Tanzanian ~27% [3]. **Likely [7]:** Kenyan ~29% [2], Uganda ~43% [3], Tanzania ~29% [2]. **Very likely [9]:** Kenyan ~67% [6], Ugandan ~11% [1], Tanzanian ~11% [1], Ethiopian ~11% [1]. **Do not know [3]:** Kenyan ~33% [1], Tanzanian ~33% [1], Ethiopian ~11% [1]. **No answer [1]:** Tanzanian 100% [1] (not shown in Fig. E.3.1).

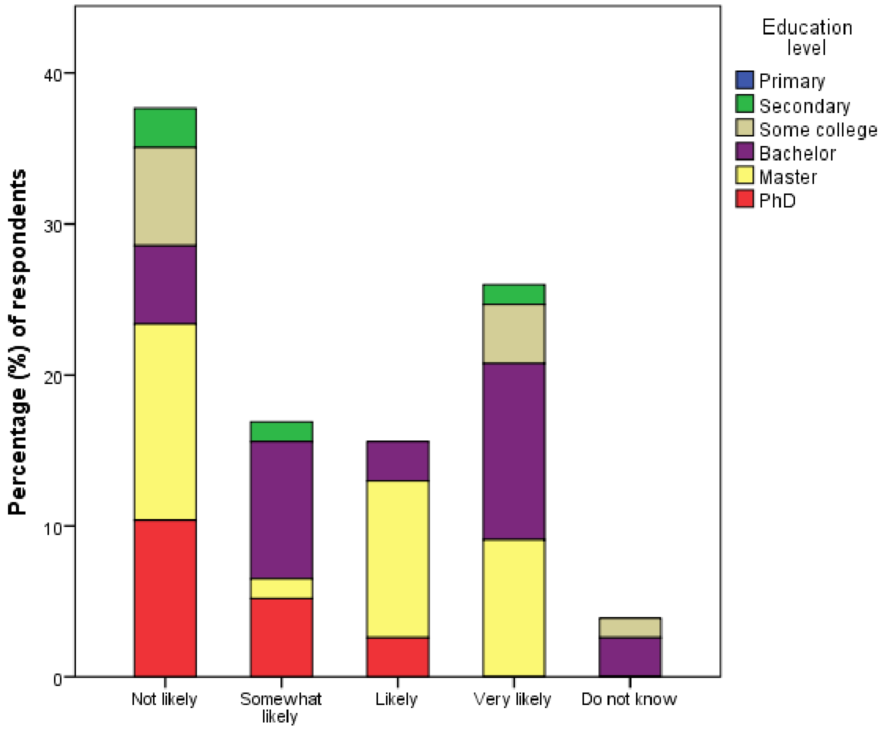


Figure E.3.2. Likelihood of Farmers' Rights becoming negatively affected due to adoption of genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by educational level (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the perceived likelihood of Farmers' Rights becoming negatively affected on the basis of educational level ($p<0.05$). Response rate: 100% (78 out of 78 participants).

Note: Numbers in brackets represents frequency of respondents. Figures may not add to 100% due to rounding. **Not likely [30]:** Secondary ~7% [2], some college ~17% [5], Bachelor ~13% [4], Master ~33% [10], PhD ~27% [8], no specified education ~3% [1] (not shown in Fig. E.3.2). **Somewhat likely [13]:** Secondary ~8% [1], Bachelor ~54% [7], Master ~8% [1], PhD ~31% [4]. **Likely [12]:** Bachelor ~17% [2], Master ~67% [8], PhD ~17% [2]. **Very likely [20]:** Secondary 5% [1], some college 15% [3], Bachelor 45% [9], Master 35% [7]. **Do not know [3]:** Some college ~33% [1], Bachelor ~67% [2].

E.4. Results from the Monte Carlo simulation model for investigating differences in perceptions of genetically modified (GM) crops and related issues on the basis of demographic factors among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders

Table E.4. Statistical output from the Monte Carlo simulation model for investigating differences in perceptions of genetically modified (GM) crops and related issues on the basis of demographic factors among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1].					
Do you pay attention to labels for food products as you buy food from the super markets?					
	Chi sq.[2]	**Deg.fr.[3]**	**P-value[4]**	**Q-value[5]**	**N[6]**
Age	7.59623	5	0.13460	0.17994	76
Cultural leaning	1.17682	1	0.27840	0.27800	78
Educational level	9.38864	4	0.04620*	0.05209	77
Family background	0.93600	1	0.34140	0.33331	78
Sex	7.40361	1	0.00840**	0.00651**	78
Income level	2.24862	5	0.83070	0.81378	72
Knowledge of agriculture and rural life	1.34915	2	0.52890	0.50937	78
Marital status	0.45833	1	0.51020	0.49840	77
Nationality	3.14012	3	0.38440	0.37052	78
Occupation	10.16818	7	0.13900	0.17924	78
Perception group	10.08003	3	0.01710*	0.01790*	77
Upbringing	0.09992	2	0.95320	0.95127	78
If yes, do you check whether it has GMO content or not?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	5.66210	5	0.25410	0.34050	59
Cultural leaning	0.15456	1	0.70240	0.69422	61
Educational level	8.00905	4	0.08170	0.09125	60
Family background	0.15456	1	0.69880	0.69422	61
Sex	0.81240	1	0.36680	0.36741	61
Income level	6.39142	5	0.24220	0.26997	52
Knowledge of agriculture and rural life	0.38735	2	0.83850	0.82393	61
Marital status	0.50280	1	0.49170	0.47827	61
Nationality	2.50076	3	0.50210	0.47515	61
Occupation	17.17870	7	0.00490**	0.01628*	61
Perception group	17.49497	3	0.00000***	0.00056***	60
Upbringing	4.67519	2	0.09940	0.09656	61
Have you ever consumed food containing GMOs?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	7.43501	10	0.60940	0.68384	76
Cultural leaning	1.50471	2	0.49640	0.47126	78
Educational level	19.32762	8	0.01570*	0.01320*	77
Family background	6.75490	2	0.03390*	0.03413*	78
Sex	2.21916	2	0.32960	0.32970	78
Income level	14.41348	10	0.15140	0.15495	72
Knowledge of agriculture and rural life	8.81457	4	0.06030	0.06591	78

Marital status	0.43064	2	0.83070	0.80628	77
Nationality	7.48057	6	0.27970	0.27868	78
Occupation	21.52028	14	0.07660	0.08902	78
Perception group	13.68645	6	0.03380*	0.03334*	77
Upbringing	3.52190	4	0.48260	0.47456	78
If no, would you be willing to consume foods containing GM products?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	5.19193	5	0.34760	0.39291	29
Cultural leaning	0.83874	1	0.39660	0.35976	31
Educational level	3.77289	4	0.41120	0.43761	30
Family background	0.87461	1	0.31210	0.34968	31
Sex	0.03279	1	0.85470	0.85632	31
Income level	5.53913	5	0.34330	0.35367	27
Knowledge of agriculture and rural life	4.55979	2	0.08940	0.10230	31
Marital status	0.23605	1	0.64340	0.62707	30
Nationality	5.81940	3	0.08140	0.12074	31
Occupation	9.28063	7	0.12940	0.23313	31
Perception group	15.63047	3	0.00060***	0.00135**	31
Upbringing	0.98897	2	0.64850	0.60988	31
How influential is your religious beliefs on your consumer acceptance of GM foods					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	13.53996	15	0.46240	0.56067	74
Cultural leaning	0.86613	3	0.84370	0.83359	76
Educational level	11.74095	12	0.46820	0.46670	75
Family background	0.40360	3	0.94340	0.93950	76
Sex	0.51123	3	0.92340	0.91642	76
Income level	12.59443	15	0.62770	0.63359	70
Knowledge of agriculture and rural life	4.88615	6	0.56040	0.55850	76
Marital status	2.09397	3	0.57410	0.55313	75
Nationality	6.91957	9	0.67080	0.64549	76
Occupation	22.83638	21	0.30050	0.35276	76
Perception group	9.16836	9	0.41380	0.42188	75
Upbringing	6.04936	6	0.42640	0.41768	76
Do you support for strict regulations and labelling in food products in your country?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	4.01982	5	0.51010	0.54657	75
Cultural leaning	0.44363	1	0.51020	0.50538	77
Educational level	18.05936	4	0.00140**	0.00120**	76
Family background	0.11858	1	0.73450	0.73058	77
Sex	0.46403	1	0.50820	0.49575	77
Income level	5.29254	5	0.37860	0.38123	71
Knowledge of agriculture and rural life	1.95333	2	0.37670	0.37657	77
Marital status	1.56964	1	0.21720	0.21026	76
Nationality	3.25264	3	0.36820	0.35429	77
Occupation	10.67738	7	0.12170	0.15332	77

Perception group	7.63302	3	0.05320	0.05424	76
Upbringing	1.22533	2	0.56230	0.54190	77
Do you support importation and sale of food products with GM contents in your country?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	10.44208	5	0.04290*	0.06364	75
Cultural leaning	0.37735	1	0.55460	0.53903	77
Educational level	10.38757	4	0.02920*	0.03438*	76
Family background	1.08318	1	0.30750	0.29799	77
Sex	0.00824	1	0.92070	0.92768	77
Income level	6.73059	5	0.23720	0.24146	71
Knowledge of agriculture and rural life	2.53791	2	0.28950	0.28112	77
Marital status	0.88950	1	0.35890	0.34561	76
Nationality	9.58969	3	0.01920*	0.02240*	77
Occupation	15.72609	7	0.01450*	0.02774*	77
Perception group	27.22715	3	0.00000***	0.00001***	76
Upbringing	2.11584	2	0.34440	0.34718	77
In your opinion, how do you think your government's attitude towards commercialisation of GMOs has changed over the last few years?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	11.90965	20	0.71670	0.91915	76
Cultural leaning	4.50472	4	0.30590	0.34199	78
Educational level	26.74891	16	0.04450*	0.04436*	77
Family background	1.35043	4	0.84040	0.85276	78
Sex	2.15794	4	0.70850	0.70674	78
Income level	13.39215	20	0.50080	0.85993	72
Knowledge of agriculture and rural life	6.72151	8	0.45710	0.56696	78
Marital status	1.96605	4	0.66720	0.74200	77
Nationality	5.14658	12	0.91010	0.95290	78
Occupation	37.49052	28	0.12250	0.10843	78
Perception group	17.14037	12	0.12390	0.14439	77
Upbringing	9.11392	8	0.29050	0.33278	78
How do you think the public's attitude towards commercialisation of GMOs has changed over the last few years?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	4.14684	10	0.92490	0.94048	76
Cultural leaning	4.44725	2	0.10830	0.10822	77
Educational level	10.14472	8	0.24580	0.25502	76
Family background	2.20747	2	0.34710	0.33163	77
Sex	0.19033	2	0.91230	0.90922	77
Income level	13.34247	10	0.19540	0.20515	71
Knowledge of agriculture and rural life	2.97830	4	0.57410	0.56146	77
Marital status	0.25472	2	0.88840	0.88042	76
Nationality	7.33242	6	0.28960	0.29120	77
Occupation	22.79695	14	0.04220*	0.06365	77
Perception group	31.00360	6	0.00010***	0.00003***	76

Upbringing	5.06483	4	0.28560	0.28071	77
How likely is your country in approving the commercialisation of GM crops in the next few years?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	20.82167	20	0.31320	0.40769	73
Cultural leaning	8.99966	4	0.05860	0.06111	75
Educational level	19.21450	16	0.24500	0.25770	74
Family background	2.10563	4	0.72980	0.71634	75
Sex	2.44331	4	0.67140	0.65482	75
Income level	14.53427	20	0.81470	0.80241	69
Knowledge of agriculture and rural life	10.72449	8	0.21610	0.21780	75
Marital status	1.36607	4	0.86750	0.85007	74
Nationality	19.28279	12	0.07910	0.08193	75
Occupation	33.06967	28	0.18330	0.23319	75
Perception group	32.66630	12	0.00330**	0.00109**	74
Upbringing	5.78553	8	0.69480	0.67124	75
Are you aware that the Kenyan government enacted the Biosafety Bill of 2009 aimed at ensuring and assuring safe development, transfer, handling and use of genetically modified organisms in Kenya?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	5.77654	5	0.25750	0.32857	75
Cultural leaning	0.27176	1	0.62890	0.60215	77
Educational level	2.93249	4	0.55850	0.56919	76
Family background	1.71111	1	0.17120	0.19084	77
Sex	3.27963	1	0.06170	0.07014	77
Income level	6.22818	5	0.25650	0.28465	71
Knowledge of agriculture and rural life	1.07250	2	0.56980	0.58494	77
Marital status	0.00022	1	0.98820	0.98816	76
Nationality	30.31111	3	0.00000***	0.00000***	77
Occupation	11.82176	7	0.12310	0.10657	77
Perception group	3.92799	3	0.24530	0.26935	76
Upbringing	0.14667	2	0.93320	0.92929	77
What do you think of the Kenyan Biosafety Act?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	15.75794	10	0.09580	0.10677	76
Cultural leaning	4.29119	1	0.03700*	0.03831*	78
Educational level	5.06504	8	0.76230	0.75060	77
Family background	2.17489	2	0.35060	0.33708	78
Sex	1.96728	2	0.39360	0.37395	78
Income level	8.05423	10	0.61400	0.62354	72
Knowledge of agriculture and rural life	1.31980	4	0.88730	0.85801	78
Marital status	2.26796	2	0.31670	0.32175	77
Nationality	10.21341	6	0.11480	0.11595	78
Occupation	30.67230	14	0.01290*	0.00616**	77
Perception group	33.48983	6	0.00010***	0.00001***	76
Upbringing	3.44969	4	0.50260	0.48557	78

Do you think that the Kenyan Biosafety Act would influence other African countries to follow suit?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	23.94208	10	0.02160*	0.00776**	71
Cultural leaning	1.23960	1	0.28230	0.26555	73
Educational level	3.95849	4	0.40630	0.41165	72
Family background	0.00829	1	0.92370	0.92744	73
Sex	1.06563	1	0.31770	0.30193	73
Income level	9.80481	5	0.07730	0.08096	67
Knowledge of agriculture and rural life	0.99713	2	0.63120	0.60740	73
Marital status	1.94460	1	0.14720	0.16317	72
Nationality	9.14878	3	0.03230*	0.02738*	73
Occupation	12.09559	14	0.47490	0.59863	73
Perception group	8.97239	3	0.02840*	0.02966*	72
Upbringing	4.24595	2	0.11850	0.11967	73
Do you support the lifting of the 2012 ban on the importation of GM food in Kenya?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	6.36603	5	0.22700	0.27221	69
Cultural leaning	0.51566	1	0.47590	0.47270	71
Educational level	13.82222	4	0.00380**	0.00788**	70
Family background	0.95750	1	0.32750	0.32782	71
Sex	1.05529	1	0.31630	0.30429	71
Income level	6.89810	5	0.22830	0.22833	65
Knowledge of agriculture and rural life	3.45228	2	0.17770	0.17797	71
Marital status	0.04317	1	0.83660	0.83541	70
Nationality	1.38836	3	0.73380	0.70826	71
Occupation	13.96151	7	0.03010*	0.05187	71
Perception group	16.48083	3	0.00080**	0.00090***	70
Upbringing	1.49346	2	0.48950	0.47391	71
Do you support the passage of the biosafety bill into law in Uganda?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	4.20849	5	0.46590	0.51981	71
Cultural leaning	0.23618	1	0.63690	0.62698	73
Educational level	5.83249	4	0.19930	0.21201	72
Family background	2.20954	1	0.14260	0.13716	73
Sex	0.01206	1	0.91010	0.91257	73
Income level	5.32630	5	0.37100	0.37737	67
Knowledge of agriculture and rural life	2.62688	2	0.26220	0.26889	73
Marital status	3.05603	1	0.07080	0.08044	72
Nationality	2.04209	3	0.59360	0.56372	73
Occupation	31.19676	7	0.00000***	0.00006***	73
Perception group	23.92752	3	0.00010***	0.00003***	72
Upbringing	5.50217	2	0.06230	0.06386	73
Do you support the Tanzanian's government's intention of revising the current regulatory framework to allow for confined field trials and ultimately commercialisation?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**

Age	4.38403	5	0.42280	0. 49555	69
Cultural leaning	0.96454	1	0.33270	0.32605	71
Educational level	4.75216	4	0.30820	0.31369	70
Family background	0.96093	1	0.33790	0.32695	71
Sex	0.77035	1	0.39280	0.38011	71
Income level	8.37361	5	0.12930	0.13681	65
Knowledge of agriculture and rural life	1.47930	2	0.46450	0.47728	71
Marital status	0.39472	1	0.54310	0.52983	70
Nationality	7.53420	3	0.04910*	0.05669	71
Occupation	23.12967	7	0.00280**	0.00162**	71
Perception group	53.10345	3	0.00000***	0.00000***	70
Upbringing	0.28299	2	0.87930	0.86806	71
Do you support the amendments made to the Biosafety Proclamation in Ethiopia that is meant to facilitate commercialization of GM crops?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	3.19746	5	0.59540	0.66957	70
Cultural leaning	0.21654	1	0.65080	0.64169	72
Educational level	6.38343	4	0.17150	0.17229	71
Family background	1.97501	1	0.16260	0.15992	72
Sex	0.06890	1	0.80040	0.79295	72
Income level	4.65884	5	0.46080	0.45892	66
Knowledge of agriculture and rural life	0.02868	2	0.98740	0.98576	72
Marital status	0.92868	1	0.35150	0.33521	71
Nationality	7.96928	3	0.03930*	0.04665*	72
Occupation	33.21175	7	0.00000***	0.00002***	72
Perception group	50.27236	3	0.00000***	0.00000***	71
Upbringing	1.50765	2	0.49070	0.47056	72
How much do you agree or disagree that East African countries should strive for a regional harmonisation of biosafety regulations and policies?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	5.60065	15	0.93270	0.98570	75
Cultural leaning	2.05522	3	0.56500	0.56102	77
Educational level	9.28904	12	0.66080	0.67806	76
Family background	7.35985	3	0.06020	0.06127	77
Sex	4.02341	3	0.25780	0.25895	77
Income level	14.34326	15	0.42800	0.49967	71
Knowledge of agriculture and rural life	8.85062	6	0.17420	0.18215	77
Marital status	1.00013	3	0.81270	0.80122	76
Nationality	30.93862	9	0.00150**	0.00030***	77
Occupation	43.93345	21	0.01940*	0.00238**	77
Perception group	40.63795	9	0.00080***	0.00001***	76
Upbringing	3.99016	6	0.69900	0.67801	77
Do you think that it is appropriate for the international community to promote use of GM crops as solution for poverty problem in Africa?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**

Age	1.33696	5	0.92960	0.93108	75
Cultural leaning	0.75467	1	0.38700	0.38500	77
Educational level	6.08721	4	0.18950	0.19273	76
Family background	0.00637	1	0.93880	0.93639	77
Sex	1.81341	1	0.18300	0.17810	77
Income level	5.01537	5	0.41880	0.41401	71
Knowledge of agriculture and rural life	1.27472	2	0.55220	0.52869	77
Marital status	0.11038	1	0.74440	0.73971	76
Nationality	1.44634	3	0.70700	0.69471	77
Occupation	18.35713	7	0.00340**	0.01046*	77
Perception group	20.46328	3	0.00020***	0.00014***	76
Upbringing	3.97278	2	0.14740	0.13719	77
What do think of the way GMO assessment is communicated to the public in your country? Is it balanced or biased towards the positive side of the GMOs?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	14.59930	15	0.37100	0.48065	71
Cultural leaning	1.93369	3	0.60450	0.58628	73
Educational level	18.40060	12	0.10060	0.10406	72
Family background	1.40156	3	0.72270	0.70517	73
Sex	2.71686	3	0.46030	0.43737	73
Income level	9.92890	15	0.84120	0.82419	67
Knowledge of agriculture and rural life	8.92232	6	0.16890	0.17799	73
Marital status	1.53134	3	0.67910	0.67506	72
Nationality	5.82249	9	0.77650	0.75754	73
Occupation	37.99412	21	0.02200*	0.01291*	73
Perception group	32.88020	9	0.00140**	0.00014***	72
Upbringing	6.44670	6	0.38520	0.37505	73
How influential are the anti-GM groups in swaying public and farmers' opinion of GMOs?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	11.28800	10	0.26440	0.33552	75
Cultural leaning	0.86919	2	0.66420	0.64753	77
Educational level	7.13231	8	0.52260	0.52243	76
Family background	2.00205	2	0.36810	0.36750	77
Sex	0.39092	2	0.82790	0.82245	77
Income level	18.16265	10	0.04640*	0.05228	71
Knowledge of agriculture and rural life	8.40122	4	0.07440	0.07794	77
Marital status	3.84590	2	0.14260	0.14618	76
Nationality	0.44399	6	0.99930	0.99845	77
Occupation	17.35639	14	0.19620	0.23768	77
Perception group	10.51138	6	0.10180	0.10470	76
Upbringing	3.08913	4	0.57070	0.54302	77
What is your view regarding the commercialisation of GM cash crops?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	17.28162	15	0.19510	0.30231	68

Cultural leaning	2.19893	3	0.51450	0.53216	70
Educational level	14.04996	12	0.25800	0.29753	69
Family background	1.22237	3	0.73230	0.74764	70
Sex	1.50183	3	0.67840	0.68185	70
Income level	15.28164	15	0.37610	0.43133	64
Knowledge of agriculture and rural life	14.68845	6	0.02950*	0.02282*	70
Marital status	1.26991	3	0.70350	0.73629	69
Nationality	15.64681	9	0.07300	0.07463	70
Occupation	37.13396	21	0.03500*	0.01625*	70
Perception group	56.43771	9	0.00010***	0.00000***	69
Upbringing	2.57336	6	0.86460	0.86017	70
What is your view regarding the commercialisation of GM food crops?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	12.74832	15	0.39050	0.62173	73
Cultural leaning	1.85856	3	0.61930	0.60227	75
Educational level	13.51545	12	0.32430	0.33271	74
Family background	2.15568	3	0.55430	0.54073	75
Sex	2.15932	3	0.55820	0.54001	75
Income level	13.76409	15	0.56540	0.54349	69
Knowledge of agriculture and rural life	10.30226	6	0.10360	0.11249	75
Marital status	1.20954	3	0.77480	0.75072	74
Nationality	10.51931	9	0.31000	0.31010	75
Occupation	41.39221	21	0.00250**	0.00501**	75
Perception group	86.98637	9	0.00000***	0.00000***	74
Upbringing	4.74248	6	0.59360	0.57724	75
How much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	16.68239	15	0.24680	0.33820	77
Cultural leaning	0.08634	3	0.99560	0.99342	77
Educational level	17.36348	12	0.12070	0.13643	76
Family background	1.13936	3	0.78750	0.76758	77
Sex	1.40423	3	0.73090	0.70454	77
Income level	10.09168	15	0.80450	0.81393	71
Knowledge of agriculture and rural life	7.80782	6	0.24700	0.25252	77
Marital status	2.25194	3	0.51770	0.52179	76
Nationality	9.17504	9	0.40840	0.42128	77
Occupation	52.32717	21	0.00350**	0.00017***	77
Perception group****	-	-	-	-	-
Upbringing	2.55356	6	0.88110	0.86243	77
How much do you agree or disagree that efforts being made to commercialise GM crops in East Africa are not wise and timely: conventional measures should be first fully exploited before embarking on use of biotechnology?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	16.30211	15	0.28020	0.36226	76

Cultural leaning	3.62151	3	0.30910	0.30534	78
Educational level	17.68858	12	0.12000	0.12548	77
Family background	0.59337	3	0.91050	0.89795	78
Sex	1.77195	3	0.63640	0.62106	78
Income level	9.31548	15	0.88740	0.86045	72
Knowledge of agriculture and rural life	2.08198	6	0.93130	0.91201	78
Marital status	0.29915	3	0.96660	0.96019	77
Nationality	10.14548	9	0.33700	0.33884	78
Occupation	35.68419	21	0.02190*	0.02372*	78
Perception group	42.29972	9	0.00010***	0.00000***	77
Upbringing	4.99235	6	0.55210	0.54479	78
How much do you agree or disagree that East Africa countries are not ready yet for GMOs: They should first develop their regulatory capacity and improve their infrastructure before they adopt GMOs?					
	Chi sq.	**Deg.fr.**	**P-value**	**Q-value**	**N**
Age	15.31676	15	0.35960	0.42885	76
Cultural leaning	2.00723	3	0.59070	0.57091	78
Educational level	14.35215	12	0.28560	0.27879	77
Family background	8.69762	3	0.02730*	0.03359*	78
Sex	1.85509	3	0.62380	0.60302	78
Income level	11.29779	15	0.74790	0.73121	72
Knowledge of agriculture and rural life	1.21223	6	0.98660	0.97628	78
Marital status	1.44769	3	0.73420	0.69440	77
Nationality	10.66183	9	0.30140	0.29960	78
Occupation	23.07932	21	0.27120	0.33976	78
Perception group	46.25847	9	0.00000***	0.00000***	77
Upbringing	12.26063	6	0.05400	0.05640	78

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2] Chi sq. = chi squared value.
[3] Deg.fr = degrees of freedom.
[4] The P-value is the statistical significance value produced by the Monte Carlo simulation model.
[5] The Q-value is the statistical significance value one would get by employing the standard chi-squared test.
[6] N = the sample size = total number of respondents for the particular question.
Note: See Appendix F and Chapter 25 (main thesis) for more information about the test statics.
*Indicate statistical significance at the 5% level.
**Indicate statistical significance at the 1% level.
***Indicate statistical significance at the 0.1% level.
**** Not applicable as the question “how much do you agree or disagree that GM crops should play a role in addressing issues of food insecurity, hunger and poverty in your country?” was used to group participants into perception groups.

E.5. Stakeholder responses, perception groups and demographic factors: Bar charts and tables

Note: Numbers in brackets represent frequency of respondent. Figures may not add to 100% due to rounding. Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in a non-governmental organisation sector. Note: PG = perception group; 1 = negative towards GM crops, 2 = somewhat positive towards GM crops, 3 = positive towards GM crops, 4 = very positive towards GM crops.

E.5.1 What do you think of the Kenyan National Biosafety Act of 2009?

Table E.5.1. Opinions of the Kenyan Biosafety Act of 2009 by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1] divided by perception group (PG)[2], occupation[3] and cultural leaning[4]; in % and [number] of total respondents [78].

	The Act was wise and timely	The Act was unwise and untimely	"Other"[5]
Nationality	Kenyan ~69% [40], Ugandan ~10% [6], Tanzanian ~10% [6], Ethiopian ~ 10% [6]	Kenyan ~67% [8], Ugandan ~17% [2], Tanzanian ~8%[1], Ethiopian ~8% [1]	Kenyan 12.5% [1], Ugandan 37.5% [3], Tanzanian 25% [2], Ethiopian 25% [2]
Perception group	PG1 ~9% [5], PG2 ~7% [4], PG3 ~27% [16], PG4 ~55% [32], no PG ~2% [1]	PG1 ~83% [10], PG3 ~8% [1], PG4 ~8% [1]	PG1 37.5% [3], PG3 37.5% [3], PG4 25% [2]
Occupation	Other ~2% [1], farmer ~3% [2], agricultural researcher ~33% [19], extension worker ~14% [8], policy-maker ~2% [1], civil servant (1) ~33% [19], civil servant (2) ~3% [2], civil servant (3) ~10% [6]	Other ~8% [1], farmer ~8% [1], extension worker ~8% [1], policy-maker ~8% [1], civil servant (3) ~67% [8]	Agricultural researcher 25% [2], extension worker 25% [2], civil servant (1) 12.5% [1], civil servant (3) 37.5% [3]
Cultural leaning	Liberal ~28% [16], moderate ~72% [42]	Moderate 100% [12]	Liberal ~11% [1], moderate ~89% [7]
Total	74.4% [58]	15.4% [12]	10.3% [8]

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2]PG1 = negative towards genetically modified (GM) crops; PG2 = somewhat positive towards GM crops; 3 = positive towards GM crops; 4 = very positive towards GM crops.
[3]Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in the non-governmental organisation sector.
[4] Response to the question "How best do you describe yourself culturally?".
[5]"Other" refers to other viewpoints.

E.5.2. Do you think that the Kenyan Biosafety Act would influence other African countries to follow suit?

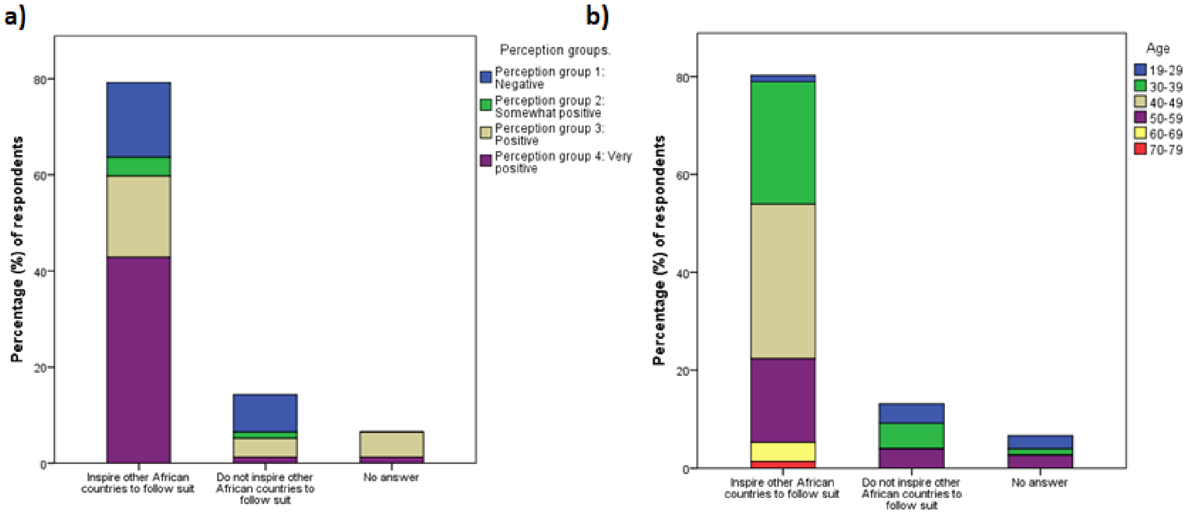


Figure E.5.2. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group (PG) and b) age that believed the Kenyan Biosafety Act of 2009 would inspire other African countries to follow suit. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the opinions on whether the Act would inspire other African countries to follow suit on the basis of perception group (p<0.05). **b)** There were significant differences in opinions on whether the Act would inspire other African countries to follow suit on the basis of age (p<0.05). Response rate a-b: ~94% (73 out of 78 respondents).

Believe that the Kenyan Biosafety Act of 2009 inspires other African countries to follow suit [62]: PG1 ~19% [12], PG2 ~5% [3], PG3 ~21% [13], PG4 ~53% [33], no PG ~2% [1] (latter not shown in Fig. E.5.2a); 19-29 ~2% [1], 30-39 ~31% [19], 40-49 ~39% [24], 50-59 ~21% [13], 60-69 ~5% [3], 70-79 ~2% [1], no specific age ~2% [1] (latter not shown in Fig. E.5.2b). **Do not believe that the Kenyan Biosafety Act of 2009 inspires other African countries to follow suit [11]:** PG1 ~55% [6], PG2 ~9% [1], PG3 ~27% [3], PG4 ~9% [1]; 19-29 ~27% [3], 30-39 ~36% [4], 50-59 ~27% [3], no specified age ~9% [1] (latter not shown in Fig. E.5.2b). **No answer [5]:** PG3 80% [4], PG4 20% [1]; 19-29 40% [2], 30-39 20% [1], 50-59 40% [2].

E.5.3. Do you support the lifting of the 2012 ban on the importation of GM food in Kenya?

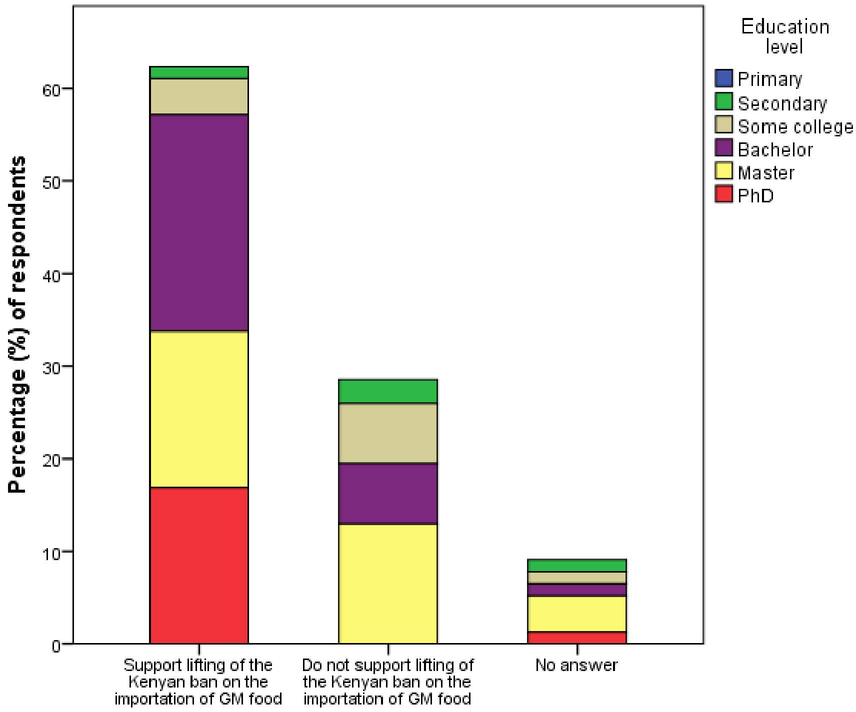


Figure E.5.3. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by educational level that supported lifting of the 2012 Kenyan ban on the importation of genetically modified (GM) food. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the perception on the lifting of the ban on the basis of educational level ($p<0.01$). Response rate: ~91% (71 out of 78 respondents).

Support lifting the Kenyan ban on the importation of GM food [48]: Secondary ~2% [1], some college ~6% [3], Bachelor ~38% [18], Master ~27% [13], PhD ~27% [13]. **Do not support lifting the Kenyan ban on the importation of GM food [23]:** Secondary ~9% [2], some college ~22% [5], Bachelor ~22% [5], Master ~43% [10], no education ~4% [1]. **No answer [7]:** Secondary ~14% [1], some college ~14% [1], Bachelor ~14% [1], Master ~43% [3], PhD ~14% [1].

E.5.4. Do you think that it is appropriate for the international community to promote use of GM crops as solution for poverty problem in Africa?

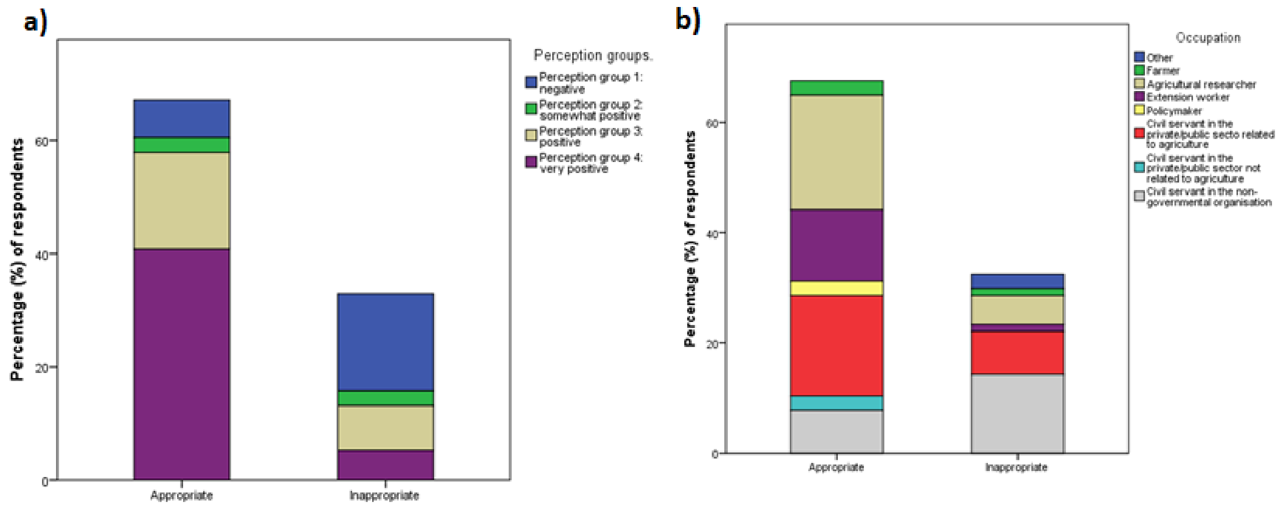


Figure E.5.4. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group (PG) and b) occupation that think it is appropriate for the international community to promote the use of genetically modified (GM) crops as a solution for poverty problem in Africa. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in opinions on the basis of perception group (p<0.001). **b)** There were significant differences in opinions on the basis of occupation (p<0.01). Response rate a-b: ~99% (77 out of 78 respondents).

<u>Appropriate [52]:</u> PG1 ~10% [5], PG2 ~4% [2], PG3 25% [13], PG4 ~ 60% [31], no PG ~2% [1] (not shown in Fig. E.5.4.); farmer ~4% [2], agricultural researcher ~31% [16], extension worker ~19% [10], policymaker ~4%[2], civil servant (1) ~27% [14], civil servant (2) ~4% [2], civil servant (3) ~10% [6]. **<u>Inappropriate [25]:</u>** PG1 52% [13], PG2 8% [2], PG3 24% [6], PG4 16% [4]; other 8% [2], farmer 4% [1], agricultural researcher 16% [4], extension worker 4% [1], civil servant (1) 24% [6], civil servant (3) 44% [11]. **<u>No answer [1] (not shown in Fig. E.5.4):</u>** PG3 100% [1]; agricultural researcher 100% [1].

E.5.5. How influential are the anti-GM groups in swaying public and farmers' opinion of GMOs?

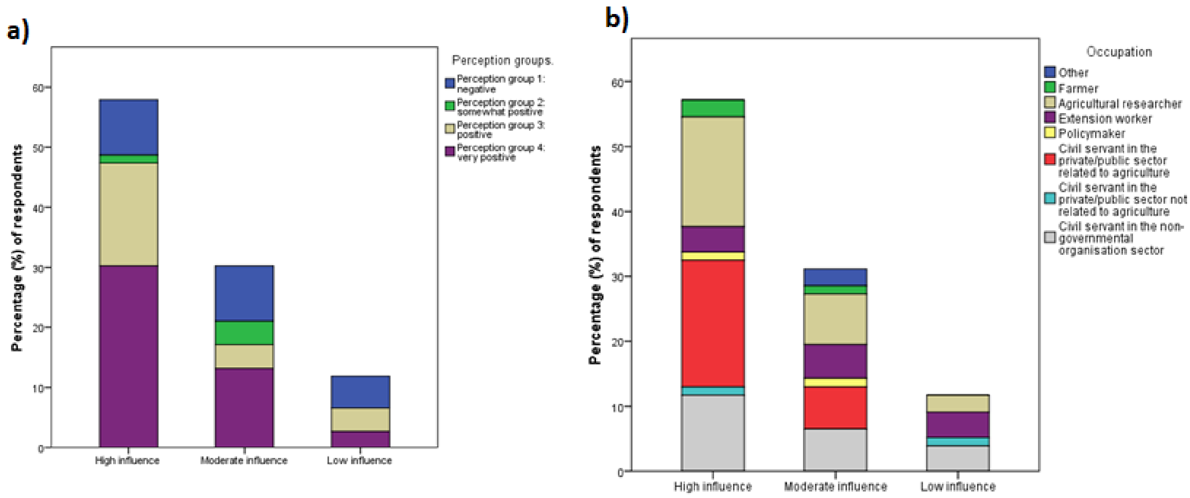


Figure E.5.5.1. Level of influence by anti-GMO (genetically modified organisms) groups on the East African public and farmer opinions of GMOs as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group (PG) and b) occupation (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were NS differences in the perceived level of influence of anti-GMO groups on the basis of perception group (p>0.05). **b)** There were NS differences in the perceived level of influence of anti-GMO groups on the basis of occupational group (p>0.05). Response rate a-b: 100% (78 out of 78 participants).

High influence [44]: PG1 ~16% [7], PG2 ~2% [1], PG3 ~30% [13], PG4 ~52% [23]; farmer ~5% [2], agricultural researcher ~30% [13], extension worker ~7% [3], policymaker ~2% [1], civil servant (1) ~34% [15], civil servant (2) ~2% [1], civil servant (3) ~20% [9]. **Moderate influence [24]:** PG1 ~29% [7], PG2 12.5% [3], PG3 12.5% [3], PG4 ~42% [10], no PG ~4% [1] (not shown in Fig. E.5.5.1); other ~8% [2], farmer ~4% [1], agricultural researcher 25% [6], extension worker ~17% [4], policymaker ~4% [1], civil servant (1) ~21% [5], civil servant (3) ~21% [5]. **Low influence [9]:** PG1 ~44% [4], PG3 ~33% [3], PG4 ~22% [2]; agricultural researcher ~22% [2], extension worker ~33% [3], civil servant (2) ~11% [1], civil servant (3) ~33% [3]. **No opinion [1] (not shown in Fig. E.5.5.1):** PG3 100% [1]; extension worker 100% [1].

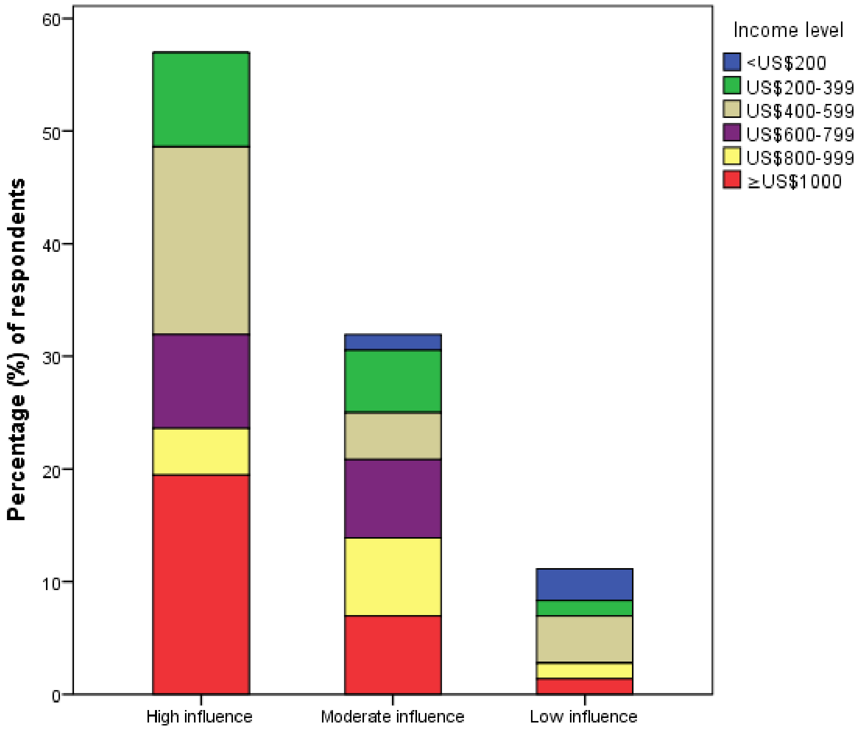


Figure E.5.5.2 Level of influence by anti-GMO (genetically modified organisms) groups on the East African public and farmer opinions of GMOs as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by income level (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were differences in the perceived level of influence of anti-GMO groups on the basis income level ($p<0.05$). Response rate: 100% (78 out of 78 participants).

High influence [44]: US$200-399 ~14% [6], US$400-599 ~27% [12], US$600-799 ~14% [6], US$800-999 ~7% [3], ≥US$1000 ~32% [14], no specified income level ~7% [3]. **Moderate influence [24]:** <US$200 ~4% [1], US$200-399 ~17% [4], US$400-599 ~13% [3], US$600-799 ~21% [5], US$800-999 ~21% [5], ≥US$1000 ~21% [5], no answer ~4% [1]. **Low influence [9]:** <US$200 ~22% [2], US$200-399 ~11% [1], US$400-599 ~33% [3], US$800-999 ~11% [1], ≥US$1000 ~11% [1], no answer ~11% [1]. **No opinion [1]:** no specified income 100% [1] (not shown in Fig. E.5.5.2).

E.5.6. What do think of the way GMO assessment is communicated to the public in your country? Is it balanced or biased towards the positive side of the GMOs?

Table E.5.6. Balance of information about genetically modified organisms (GMOs) communicated to the East African public as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1] divided by nationality, perception group (PG)[2], and occupation[3]; in % and [number] of total respondents [78].

	Total	Nationality	Perception groups (PG)	Occupation
Biased towards the positive	29.5 [23]	Kenyan ~70% [16], Ugandan ~13% [3], Tanzanian ~9% [2], Ethiopian ~9% [2]	PG1 ~57% [13], PG2 ~9% [2], PG3 ~13% [3], PG4 ~17% [4], no PG ~4% [1]	Other ~4% [1], farmer ~9% [2], agricultural researcher ~4% [1], extension worker ~9% [2], policymaker ~4% [1], civil servant (1) ~26% [6], civil servant (2) ~4% [1], civil servant (3) ~39% [9]
Biased towards the negative	29.5 [23]	Kenyan ~61% [14], Ugandan ~13% [3], Tanzanian ~9% [2], Ethiopian ~17% [4]	PG1 ~4% [1], PG2 ~4% [1], PG3 ~30% [7], PG4 ~61% [14]	Farmer ~4% [1], agricultural researcher ~48% [11], policymaker ~4% [1], civil servant (1) ~30% [7], civil servant (3) ~13% [3]
Balanced	29.5 [23]	Kenyan ~65% [15], Ugandan ~17% [4], Tanzanian ~9% [2], Ethiopian ~9% [2]	PG1 ~4%[1], PG2 ~4% [1], PG3 ~26% [6], PG4 ~65% [15]	Other ~4% [1], agricultural researcher ~30% [7], extension worker ~35% [8], civil servant (1) ~17% [4], civil servant (2) ~4% [1], civil servant (3) ~9% [2]
Biased towards the positive and the negative	5.1 [4]	Kenyan 50% [2], Ugandan 25% [1], Tanzanian 25& [1]	PG1 75% [3], PG3 25% [1]	Civil servant (1) 25% [1], civil servant (3) 75% [3]
Do not know	5.1 [4]	Kenyan 25% [1], Tanzanian 50% [2], Ethiopian 25% [1]	PG3 75% [3], PG4 25% [1]	Agricultural researcher 50% [2], extension worker 25% [1], civil servant (1) 25% [1]
No answer	1.3 [1]	Kenyan 100% [1]	PG4 100% [1]	Civil servant (1) 100% [1]

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2]PG1 = negative towards GM crops; PG2 = somewhat positive towards GM crops; 3 = positive towards GM crops; 4 = very positive towards GM crops.
[3]Civil servant (1) = civil servant employed in the public/private sector related to agriculture; civil servant (2) = civil servant employed in the public/private sector not related to agriculture; civil servant (3) = civil servant employed in the non-governmental organisation sector.
Note: Figures may not add to 100% due to rounding.

E.5.7. What is your view regarding commercialisation of GM food crops (e.g. Bt maize) and cash crops (e.g. Bt cotton) in your country?

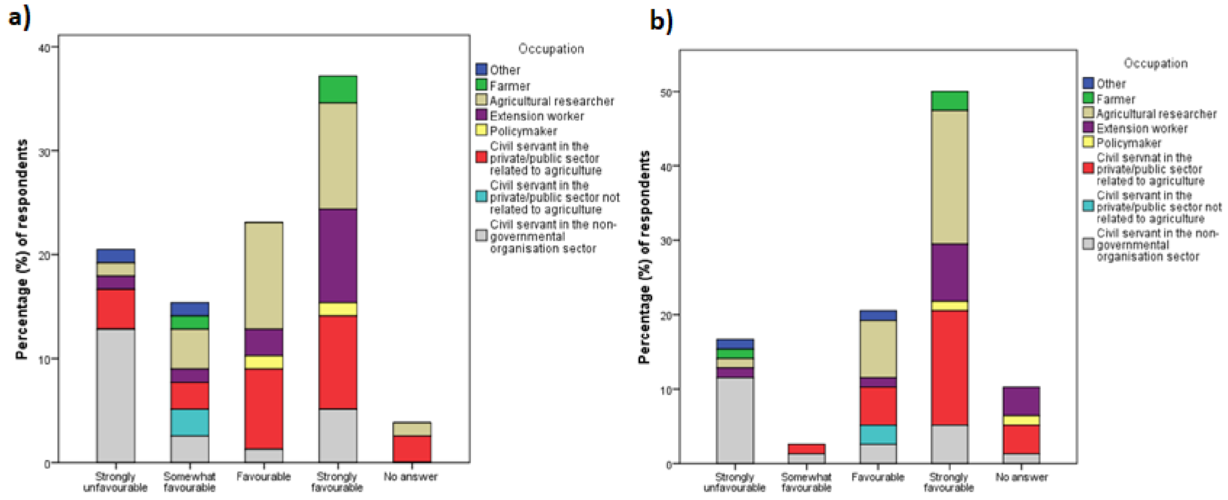


Figure E.5.7.1. Opinions of the commercialisation of genetically modified (GM) a) food crops and b) cash crops by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by occupational group (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative **a)** There were significant differences in the opinions of commercialisation of GM food crops on the basis of occupation ($p<0.01$). Response rate: ~96% (75 out of 78 respondents). **b)** There were significant differences in the opinions of commercialisation of GM cash crops on the basis of occupation ($p<0.05$). Response rate: ~90% (70 out of 78 participants).

GM food crops. **Strongly unfavourable [16]:** Other ~6% [1], agricultural researcher ~6% [1], extension worker ~6% [1], civil servant (1) ~19% [3], civil servant (3) ~62% [10]. **Somewhat favourable [12]:** Other ~8% [1], farmer ~8% [1], agricultural researcher 25% [3], extension worker ~8% [1], civil servant (1) ~17% [2], civil servant (2) ~17% [2], civil servant (3) ~17% [2]. **Favourable [18]**: Agricultural researcher ~44% [8], extension worker ~11% [2], policymaker ~6% [1], civil servant (1) ~33% [6], civil servant (3) ~6% [1]. **Strongly favourable [29]**: Farmer ~7% [2], agricultural researcher ~28% [8], extension worker ~24% [7], policymaker ~3% [1], civil servant (1) ~24% [7], civil servant (3) ~14% [4]. **No answer [3]:** Agricultural researcher ~33% [1], civil servant (1) ~67% [2].

GM cash crops. **Strongly unfavourable [13]**: Other ~8% [1], farmer ~8% [1], agricultural researcher ~8% [1], extension worker ~8% [1], civil servant (3) ~69% [9]. **Somewhat favourable [2]**: Civil servant (1) 50% [1], civil servant (3) 50% [1]. **Favourable [16]:** Other ~6% [1], agricultural researcher ~38% [6], extension worker ~6% [1], civil servant (1) 25% [4], civil servant (2) ~13% [2], civil servant (3) ~13% [2]. **Strongly favourable [39]:** Farmers ~5% [2], agricultural researcher ~36% [14], extension worker ~15% [6], policymaker ~3% [1], civil servant (1) ~31% [12], civil servant (3) ~10% [4]. **No answer [8]:** extension worker 37.5% [3], policymaker 12.5% [1], civil servant (1) 12.5% [3], civil servant (3) 37.5% [1].

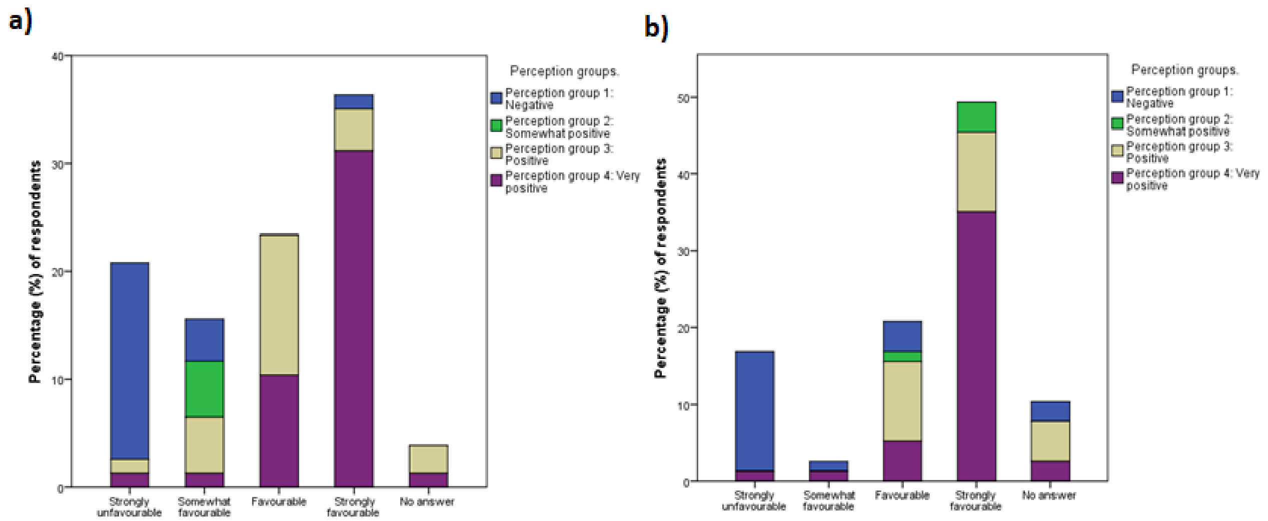


Figure E.5.7.2. Opinions of the commercialisation of genetically modified (GM) a) food crops and b) cash crops by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by perception group (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the opinions of commercialisation of GM food crops on the basis of perception group ($p<0.001$). Response rate: ~96% (75 out of 78 participants). **b)** There were significant differences in the opinions of commercialisation of GM cash crops on the basis of perception group ($p<0.001$). Response rate: ~90% (70 out of 78 participants).

GM food crops. **Strongly unfavourable [16]:** PG1 ~88% [14], PG3 ~6% [1], PG4 ~6% [1]. **Somewhat favourable [12]:** PG1 25% [3], PG2 ~33% [4], PG3 ~33% [4], PG4 ~8% [1]. **Favourable [18]**: PG3 ~56% [10], PG4 ~44% [8]. **Strongly favourable [29]**: PG1 ~3% [1], PG3 ~ 10% [3], PG4 ~83% [24], no PG ~3% [1] (not shown in Fig. E.5.7.2a). **No answer [3]:** PG3 [2], PG4 [1].

GM cash crops. **Strongly unfavourable [13]**: PG1 ~92% [12], PG4 ~8% [1]. **Somewhat favourable [2]**: PG1 50% [1], PG4 50% [1]. **Favourable [16]:** PG1 ~19% [3], PG2 ~6% [1], PG3 50% [8], PG4 25% [4]. **Strongly favourable [39]:** PG2 ~8% [3], PG3 ~20% [8], PG4 ~69% [27], no PG ~3% [1] (not shown in Fig. E.5.7.2b). **No answer [8]:** PG1 25% [2], PG3 50% [4], PG4 25% [2].

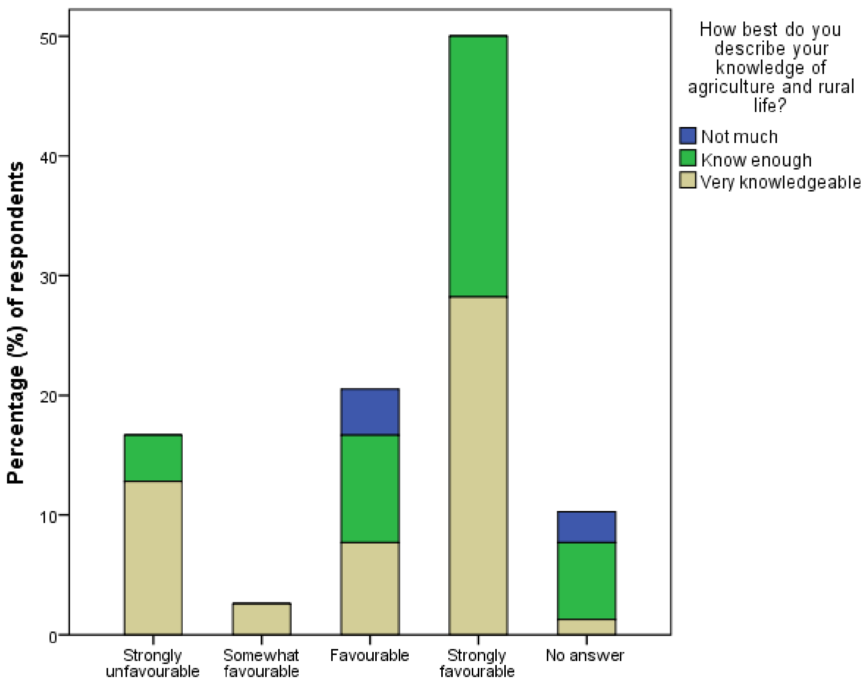


Figure E.5.7.3. Opinions of the commercialisation of genetically modified (GM) cash crops by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by knowledge of agriculture and rural life (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions of commercialisation of GM cash crops on the basis of knowledge of agriculture and rural life ($p<0.05$). Response rate: ~90% (70 out of 78 participants).

Strongly unfavourable [13]: Know enough ~23% [3], very knowledgeable ~77% [10]. **Somewhat favourable [2]:** Very knowledgeable 100% [2]. **Favourable [16]:** Not much ~19% [3], know enough ~44% [7], very knowledgeable ~38% [6]. **Strongly favourable [39]:** Know enough ~44% [17], very knowledgeable ~56% [22]. **No answer [8]:** not much 25% [2], know enough ~63% [5], very knowledgeable ~13% [1].

E.5.8. How much do you agree or disagree that efforts being made to commercialize GM crops in East Africa are not wise and timely: Conventional measures should be first fully exploited before embarking on use of biotechnology?

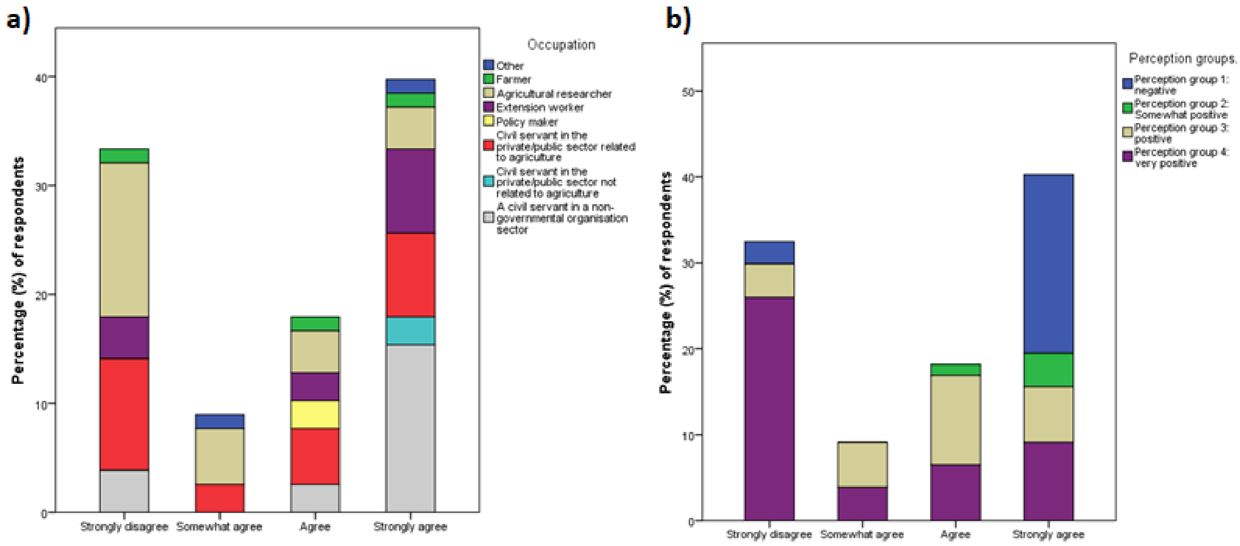


Figure E.5.8. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) occupation and b) perception group that agreed or disagreed that conventional measures should be fully exploited before the use of biotechnology. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative**. a)** There were significant differences in the opinions of conventional measures on the basis of occupational group ($p<0.05$). Response rate: 100 % (78 out of 78 respondents). **b)** There were significant differences in the opinions of conventional measures on the basis of perception group ($p<0.001$). Response rate a-b: 100 % (78 out of 78 participants).

Strongly disagree: Farmer ~4% [1], agricultural researcher ~42% [11], extension worker ~12% [3], civil servant (1) ~30% [8], civil servant (3) ~12% [3]; PG1 ~8% [2], PG3 ~12% [3], PG4 ~77% [20], no PG ~4% [1]. **Somewhat agree:** Other ~14% [1], agricultural researcher ~57% [4], civil servant (1) ~28% [2]; PG3 ~57% [4], PG4 ~43% [3]. **Agree:** Farmer ~7% [1], agricultural researcher ~21% [3], extension worker ~14% [2], policy maker ~14% [2], civil servant (1) ~28% [4], civil servant (3) ~14% [2]; PG2 ~7% [1], PG3 ~57% [8], PG4 ~36% [5]. **Strongly agree**: Other ~3% [1], farmer ~3% [1], agricultural researcher ~10% [3], extension worker ~19% [6], civil servant (1) ~19% [6], civil servant (2) ~6% [2], civil servant (3) 39% [12]; PG1 ~52% [16], PG2 ~10% [3], PG3 ~16% [5], PG4 ~23% [7].

E.5.9. How much do you agree or disagree that East Africa countries are not ready yet for GMOs: They should first develop their regulatory capacity and improve their infrastructure before they adopt GMOs?

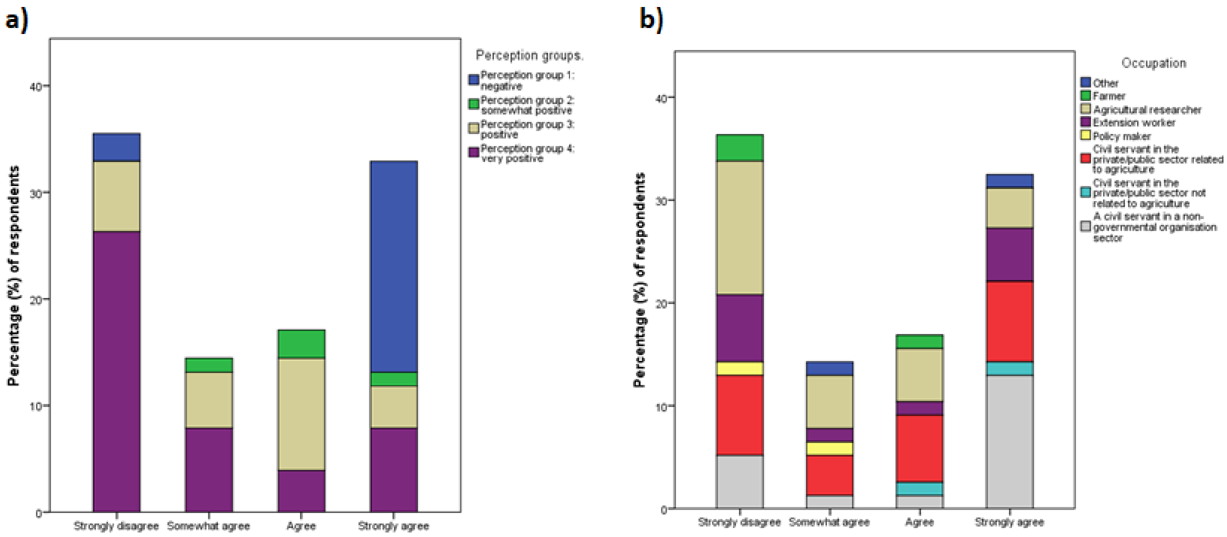


Figure E.5.9.1. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group and b) occupation that disagreed or agreed that East African countries should fully develop their regulatory capacity and improve their infrastructure before adopting genetically modified organisms (GMOs). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the opinions of infrastructural and regulatory improvements on the basis of perception group ($p<0.001$). **b)** There were significant differences in the opinions of infrastructural and regulatory improvements on the basis of occupation group ($p>0.05$). Response rate a-b: 100 % (78 out of 78 participants).

Strongly disagree: PG1 ~7% [2], PG3 ~18% [5], PG4 ~71% [20], no PG ~4% [1]; other ~ 9% [1], agricultural researcher ~ 36% [4], extension worker ~ 9% [1], policymaker ~ 9% [1], civil servant (1) ~ 27% [3], civil servant (3) ~9% [1]. **Somewhat agree:** PG2 ~9% [1], PG3 ~36% [4], ~55% PG4 [6]; other ~ 9% [1], agricultural researcher ~ 36% [4], extension worker ~ 9% [1], policymaker ~ 9% [1], civil servant (1) ~ 27% [3], civil servant (3) ~9% [1]. **Agree:** PG2 ~ 15% [2], PG3 ~62% [8], PG4 ~23% [3]; farmer ~8% [1], agricultural researcher ~30% [4], extension worker ~ 8% [1], civil servant (1) ~38% [5], civil servant (2) ~ 8% [1], civil servant (3) ~ 8% [1]. **Strongly agree:** PG1 60% [15], PG2 4% [1], PG3 12% [3], PG4 24% [6]; other 4% [1], agricultural researcher 12% [3], extension worker 16% [4], civil servant (1) 24% [6], civil servant (2) 4% [1], civil servant (3) 40% [10].

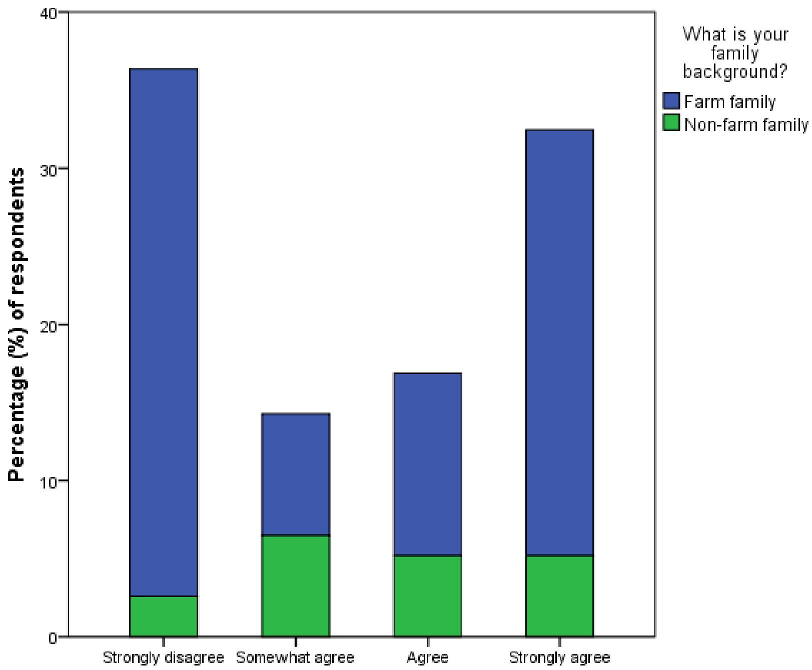


Figure E.5.9.2. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by family background that agreed that East African countries should fully develop their regulatory capacity and improve their infrastructure before adopting genetically modified organisms (GMOs). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the opinions of infrastructural and regulatory improvements on the basis of family background ($p<0.05$). Response rate: 100 % (78 out of 78 participants).

Strongly disagree [28]: Farm family ~93% [26], non-farm family ~7% [2]. **Somewhat agree [11]:** Farm family ~55% [6], non-farm family ~45% [5]. **Agree [13]:** Farm family ~69% [9], non-farm family ~31% [4]. **Strongly agree [25]:** Farm family 84% [21], non-farm family 16% [4]. **No opinion:** Farm family 100% [1] (not shown in Fig. E.5.9.2).

E.5.10. How do you think the public's attitude towards commercialisation of GMOs has changed over the last few years?

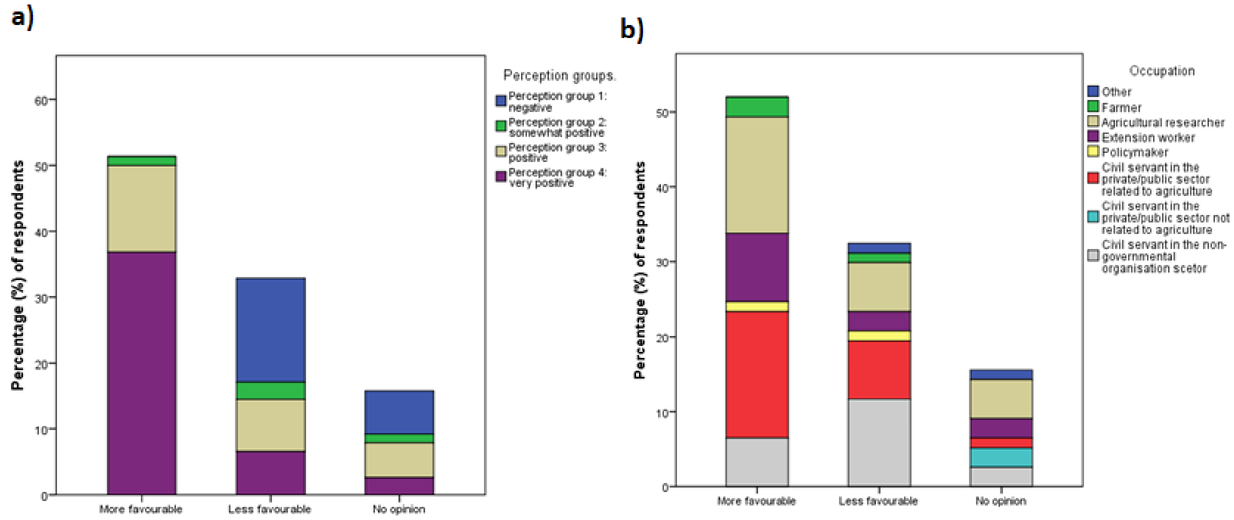


Figure E.5.10. Recent public attitude changes towards genetically modified organisms (GMOs) in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group (PG) and b) occupation (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the perceived public attitude change on the basis of perception group ($p<0.001$). **b)** There were significant differences in the perceived public attitude change on the basis of occupational group ($p<0.05$). Response rate a-b: ~99% (77 out of 78 participants).

More favourable [40]: Farmer 5% [2], agricultural researcher 30% [12], extension worker 17.5% [7], policymaker 2.5% [1], civil servant (1) 32.5% [13], civil servant (3) 12.5% [5]; PG2 2.5% [1], PG3 25% [10], PG4 70% [28], no PG 2.5% [1] (not shown in Fig.5.11a). **Less favourable [25]:** Other 4% [1], farmers 4% [1], agricultural researcher 20% [5], extension worker 8% [2], policymaker 4% [1], civil servant (1) 24% [6], civil servant (3) 36% [9]; PG1 48% [12], PG2 8% [2], PG3 24% [6], PG4 20% [5]. **No opinion [12]:** Other ~8% [1], agricultural researcher ~33% [4], policymaker ~17% [2], civil servant (1) ~8% [1], civil servant (2) ~17% [2], civil servant (3) ~17% [2]; PG1 ~42% [5], PG2 ~8% [1], PG3 ~33% [4], PG4 ~17% [2]. **No answer [1] (not shown in Fig. 5.11):** civil servant (3) 100% [1]; PG1 100% [1].

E.5.11. How do you think your government's attitude towards commercialisation of GMOs has changed over the last few years?

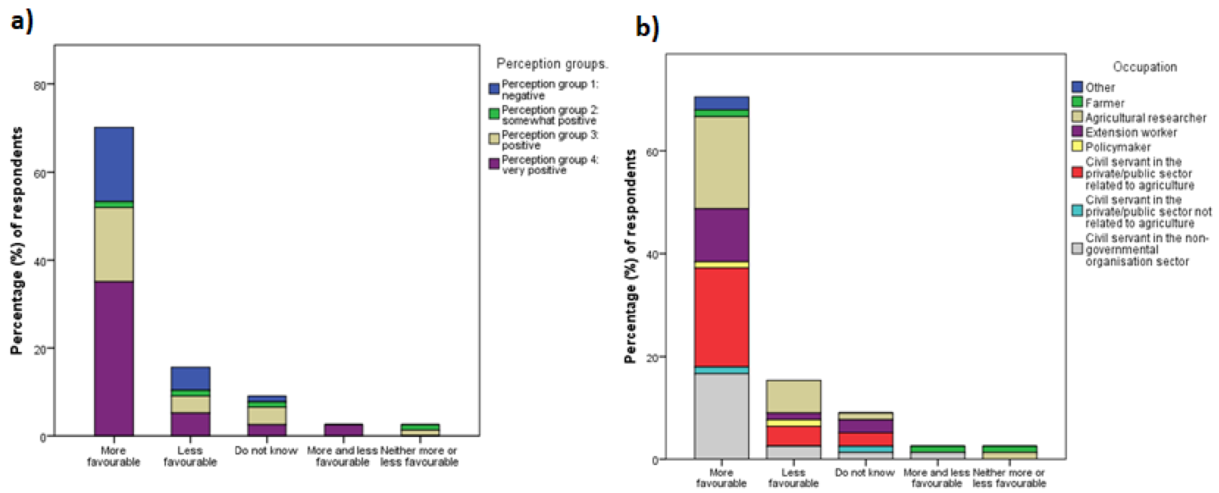


Figure E.5.11.1. Recent governmental attitude change towards genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) perception group (PG) and b) occupation (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were NS differences in the perceived governmental attitude change on the basis of perception group (p>0.05). **b)** There were NS differences in the perceived governmental attitude change on the basis of occupational group (p>0.05). Response rate a-b: 100% (78 out of 78 participants).

More favourable [55]: PG1 ~24% [13], PG2 ~2% [1], PG3 ~24% [13], PG4 ~49% [27], no PG ~2% [1] (not shown in Fig. E.5.10.1a); other ~2% [1], farmer ~2% [1], agricultural researcher ~25% [14], extension worker ~15% [8], policymaker ~2% [1], civil servant (1) ~27% [15], civil servant (2) ~2% [1], civil servant (3) ~24% [13]. **Less favourable [12]:** PG1 ~33% [4], PG2 ~8% [1], PG3 25% [3], PG4 ~33% [4]; agricultural researcher ~42% [5], extension worker ~8% [1], policymaker ~8% [1], civil servant (1) 25% [3], civil servant (3) ~17% [2]. **Do not know [7]:** PG1 ~14% [1], PG2 ~14% [1], PG3 ~43% [3], PG4 ~29% [2]; agricultural researcher ~14% [1], extension worker ~29% [2], civil servant (1) ~29% [2], civil servant (2) ~14% [1], civil servant (3) ~14% [1]. **Both more and less favourable [2]:** PG4 100% [2]; farmer 50% [1], civil servant (3) 50% [1]. **Neither more or less favourable [2]:** PG2 50% [1], PG3 50% [1]; farmer 50% [1], agricultural researcher 50% [1].

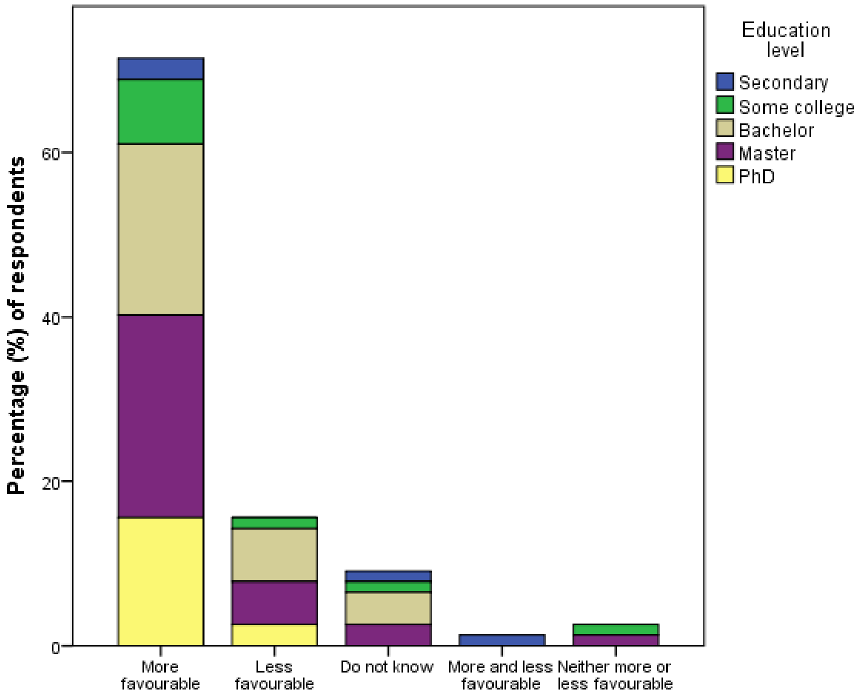


Figure E.5.11.2. Recent governmental attitude change towards genetically modified (GM) crops in East Africa as perceived by Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by educational level (in % of respondents). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in the perceived governmental attitude change on the basis of educational level ($p<0.05$). Response rate: 100% (78 out of 78 participants).

More favourable [55]: Secondary ~4% [2], some college ~11% [6], Bachelor ~29% [16}, Master ~35% [19], PhD ~22% [12]. **Less favourable [12]:** Some college ~8% [1], Bachelor ~42% [5], Master ~33% [4], PhD ~17% [2]. **Both more and less favourable [2]**: Secondary 50% [1], no specified education 50% [1] (not shown in Fig. E.5.10.2). **Neither more or less favourable [2]:** Some college 50% [1], Master 50% [1]. **Do not know [7]:** Secondary ~14% [1], some college ~14% [1], Bachelor ~43% [3], Master ~29% [2].

E.5.12. How likely is your country in approving the commercialisation of GM crops in the next few years?

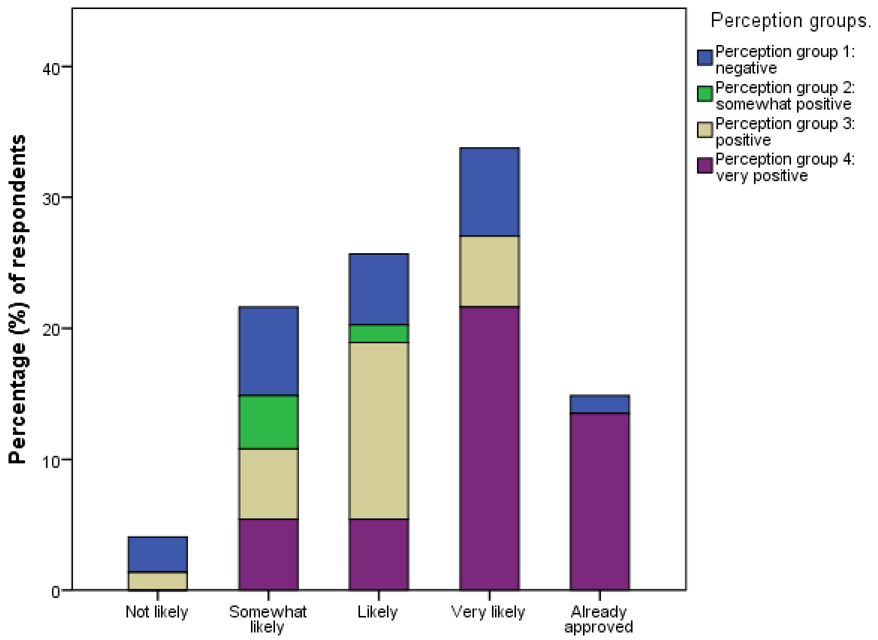


Figure E.5.12. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by perception group that perceived it as likely or unlikely that genetically modified (GM) crops would become commercialised in their country within the next few years. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative**.** There were significant differences in the perceived perceived likelihood of commercialisation on the basis of perception group (p<0.01). Note: "Already approved" refers to whether the government has already approved for commercialisation. Response rate: ~96% (75 out of 78 participants).

Not likely: PG1 50% [2], PG3 25% [1], no PG 25% [1] (not shown in Fig. E.5.12). **Somewhat likely:** PG1 ~31% [5], PG2 ~19% [3], PG3 25% [4], PG4 25% [4]. **Likely:** PG1 ~21% [4], PG2 ~5% [1], PG3 ~53% [10], PG4 ~21% [4]. **Very likely:** PG1 20% [5], PG3 16% [4], PG4 64% [16]. **Already approved:** PG1 ~9% [1], PG4 ~91% [10].

E.5.13. Consumption, labelling, sale and importation of transgenic food products

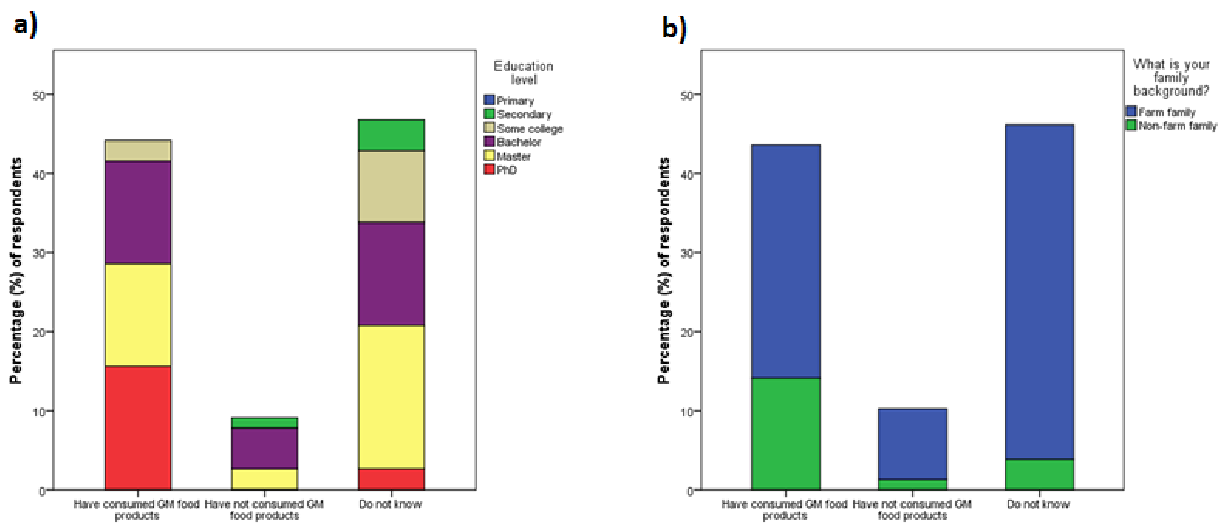


Figure E.5.13.1. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) educational level and b) family background that had consumed a genetically modified (GM) food product. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in terms of whether participants had consumed GM food products on the basis of educational level ($p<0.05$). **b)** There were significant differences in terms of whether participants had consumed GM food products on the basis of family background ($p<0.05$). Response rate a-b: 100% (78 out of 78 participants).

Have consumed GM food products [34]: Some college ~6% [2], bachelor ~29% [10], master ~29% [10], PhD ~35% [12]; farm family ~68% [23], non-farm family ~32% [11]. **Have not consumed GM food products [8]:** Secondary 12.5% [1], bachelor 50% [4], master 25% [2]; no specified educational level 12.5% [1] (not shown in Fig. E.5.13.1a); farm family 87.5% [7], non-farm family 12.5% [1]. **Do not know [36]:** Secondary ~8% [3], some college ~ 19% [7], bachelor ~ 28% [10], master ~ 39% [14], PhD ~ 6% [2]; farm family ~92% [33], non-farm family ~8% [3].

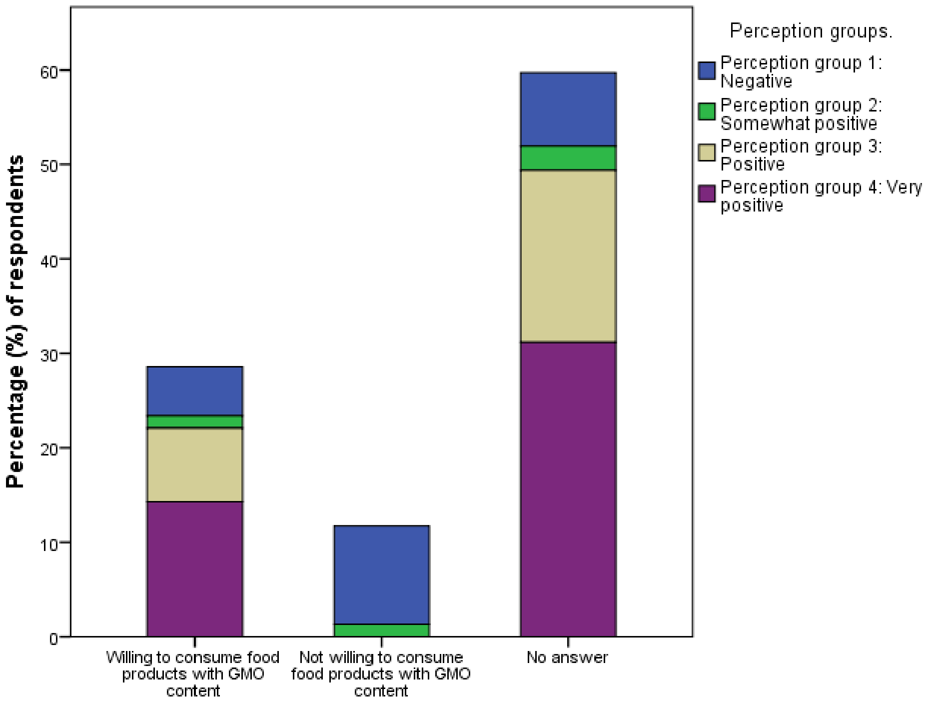


Figure E.5.13.2. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by perception group that were willing to consume food products with GMO (genetically modified organism) content. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant differences in terms of whether participants were willing to consume GM food products on the basis of perception group (p<0.001). Response rate: ~40% (31 out of 78 respondents). Please note that the low response rate was because the question presupposed that participants were unsure of or had not consumed GMO products in the past.

Willing to consume food products with GMO content [22]: PG1 ~18% [4], PG2 ~5% [1], PG3 ~27% [6], PG4 50% [11]. **Not willing to consume food products with GMO content [9]:** PG1 ~89% [8], PG2 ~11% [1]. **No answer [47]:** PG1 ~13% [6], PG2 ~4% [2], PG3 ~30% [14], PG4 ~ 51% [24], no PG ~2% [1] (not shown in Fig. E.5.13.2).

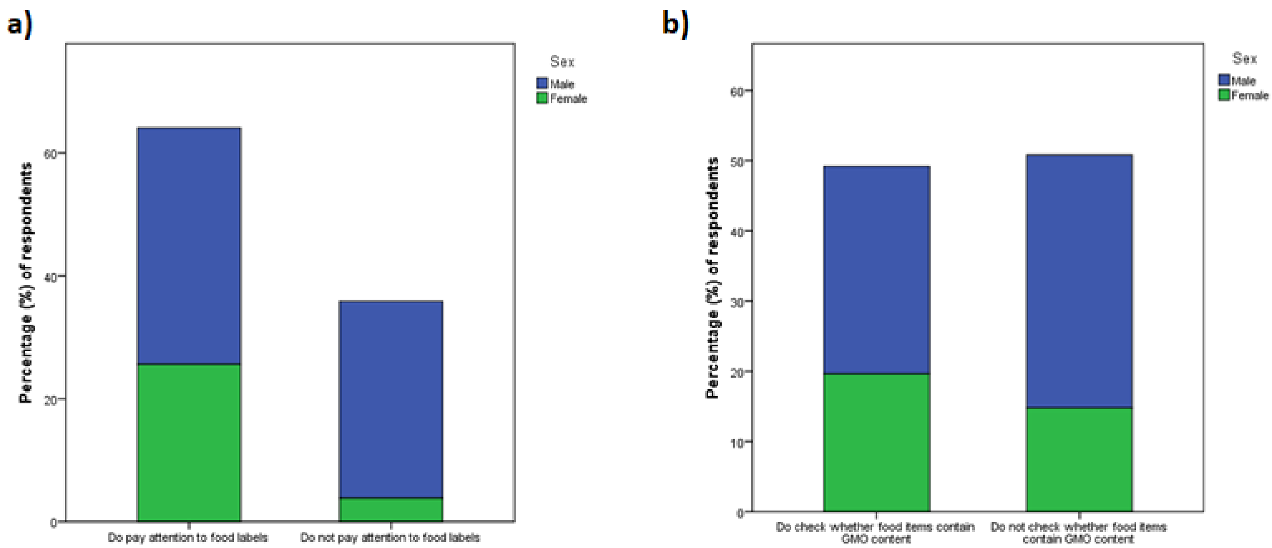


Figure E.5.13.3. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by sex that a) pay attention to food labels and b) check whether food products contain content originating from a genetically modified organism (GMO). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in terms of whether participants paid attention to food labels on the basis of sex ($p<0.01$). Response rate: 100% (78 respondents). **b)** There were NS differences in terms of whether participants checked whether food items contained GMO content on the basis of sex (>0.05). Response rate: ~78% (61 out of 78 participants). Please note that the relatively low response rate was because the question presupposed that participants paid attention to food labels.

Pay attention to food labels [50]: Male 60% [30], female 40% [20]. **Do not pay attention to food labels [28]:** Male ~89% [25], female ~11% [3]. **Check whether food products contain GMO content [30]:** Male 60% [18], female 40% [12]. **Do not check whether food products contain GMO content [31]:** Male ~71% [22], female ~29% [9]. **No answer [17]:** Male ~88% [15], female ~12% [2].

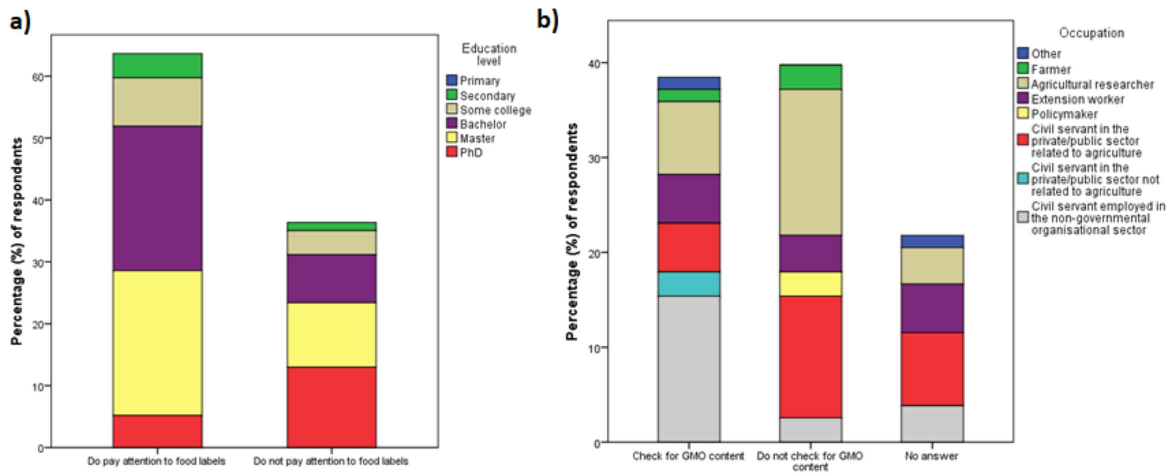


Figure E.5.13.4. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders a) divided by educational level that paid attention to food labels and b) divided by occupational group that checked whether food products contain content originating from a genetically modified organism (GMO). Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in terms of whether participants paid attention to food labels on the basis of educational level ($p<0.05$). Response rate: 100% (78 out of 78 participants). **b)** There were significant differences in terms of whether participants checked whether food items contained GMO content on the basis of occupation ($p<0.01$). Response rate: ~78% (61 out of 78 participants). Please note that the relatively low response rate was because the question presupposed that participants paid attention to food labels.

<u>Pay attention to food labels [50]:</u> Secondary 6% [3], some college 12% [6], Bachelor 36% [18], Master 36% [18], PhD 8% [4], no education 2% [1] (not shown in Fig. E.5.13.4a). **<u>Do not pay attention to food labels [28]:</u>** Secondary ~4% [1], some college ~11% [3], Bachelor ~21% [6], Master ~29% [8], PhD ~36% [10]. **<u>Check whether food products contain GMO content [30]:</u>** Other ~3% [1], farmer ~3% [1], agricultural researcher 20% [6], extension worker ~13% [4], civil servant (1) ~13% [4], civil servant (2) ~7% [2], civil servant (3) 40% [12]. **<u>Do not check whether food products contain GMO content [31]:</u>** Farmer ~6% [2], agricultural researcher ~39% [12], extension worker ~10% [3], policymaker ~6% [2], civil servant (1) ~32% [10], civil servant (3) ~6% [2]. **<u>No answer [17]:</u>** Other ~6% [1], agricultural researcher ~18% [3], extension worker ~24% [4], civil servant (1) ~35% [6], civil servant (3) ~18% [3].

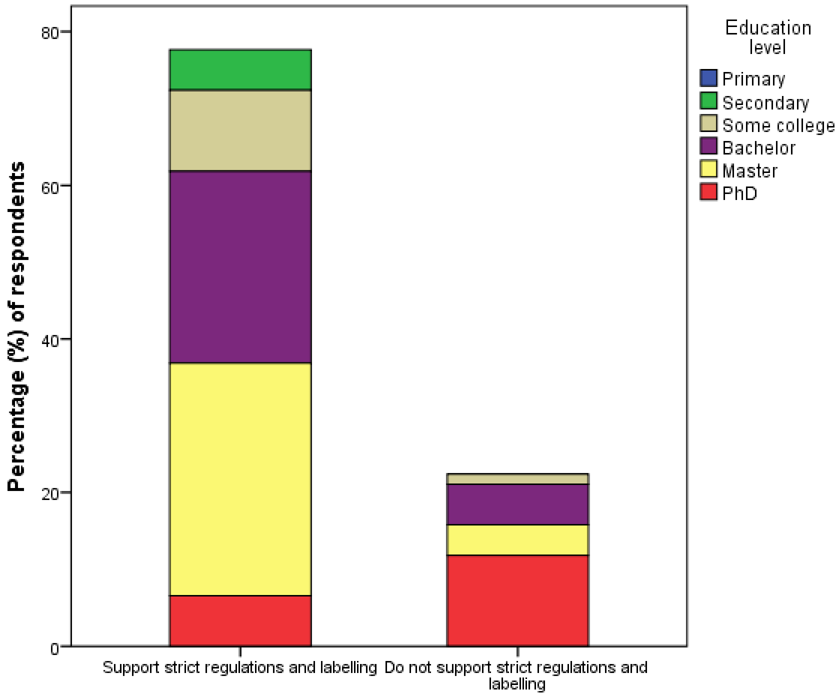


Figure E.5.13.5. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by educational level that supported strict regulations and labelling of food products in their country. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. There were significant in the level of support for strict regulations and labelling on the basis of educational level ($p<0.05$). Response rate: ~99% (77 out of 78 participants).

Support strict regulations and labelling [59]: Secondary ~7% [4], some college ~14% [8], Bachelor ~32% [19], Master ~39% [23], PhD ~8% [5]. **Do not support strict regulation and labelling [18]:** Some college ~6% [1], Bachelor ~22% [4], Master ~17% [3], PhD 50% [9], no specified education ~6% [1] (not shown in Fig. E.5.13.5). **No answer:** Bachelor [1] (not shown in Fig. E.5.13.5).

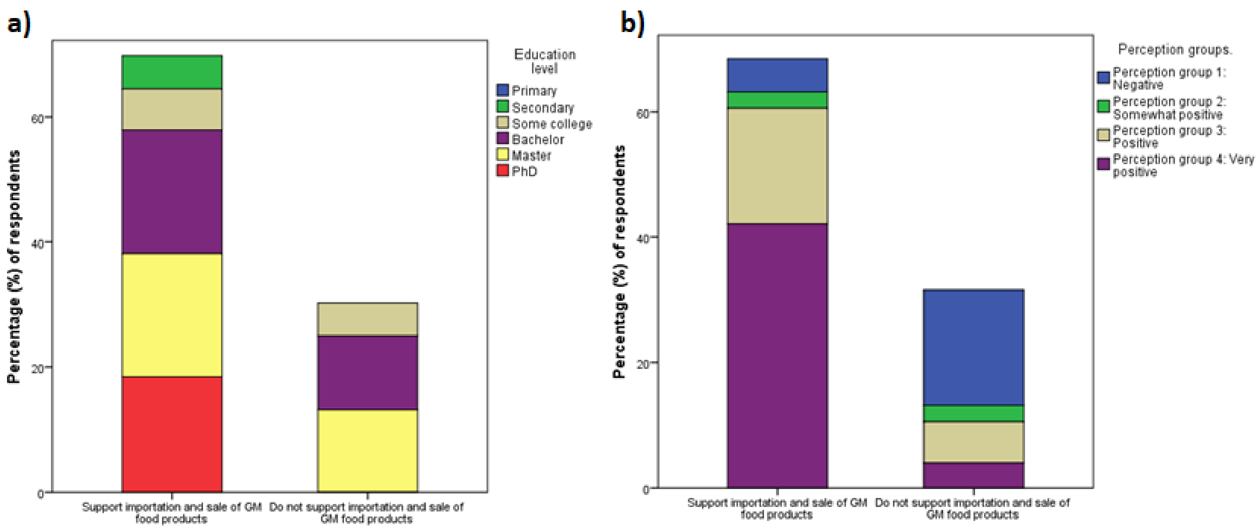


Figure E.5.13.6. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) educational level and b) perception group that supported importation and sale of genetically modified (GM) food products. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the level of support for importation and sale of GM food products on the basis of educational level ($p<0.05$). **b)** There were significant differences in the level of support for importation and sale of GM food products on the basis of perception group ($p<0.001$). Response rate a-b: ~99% (77 out of 78 participants).

Support importation and sale of GM food products [53]: Secondary ~8% [4], some college ~9% [5], Bachelor ~28% [15], Master ~28% [15], PhD ~26% [14]; PG1 ~8% [4], PG2 ~4% [2], PG3 ~26% [14], PG4 ~60% [32], no PG ~2% [1] (not shown in Fig. E.13.6**b)**. **Do not support importation and sale of GM food products [24]:** Some college ~17% [4], Bachelor ~38% [9], Master ~ 42% [10], no specified education ~4% [1] (not shown in Fig. E.5.13.6a); PG1 ~58% [14], PG ~8% [2], PG3 ~21% [5], PG4 ~13% [3]. **No answer [1] (not shown in Fig. E.5.13.6):** Master 100% [1]; PG3 [1].

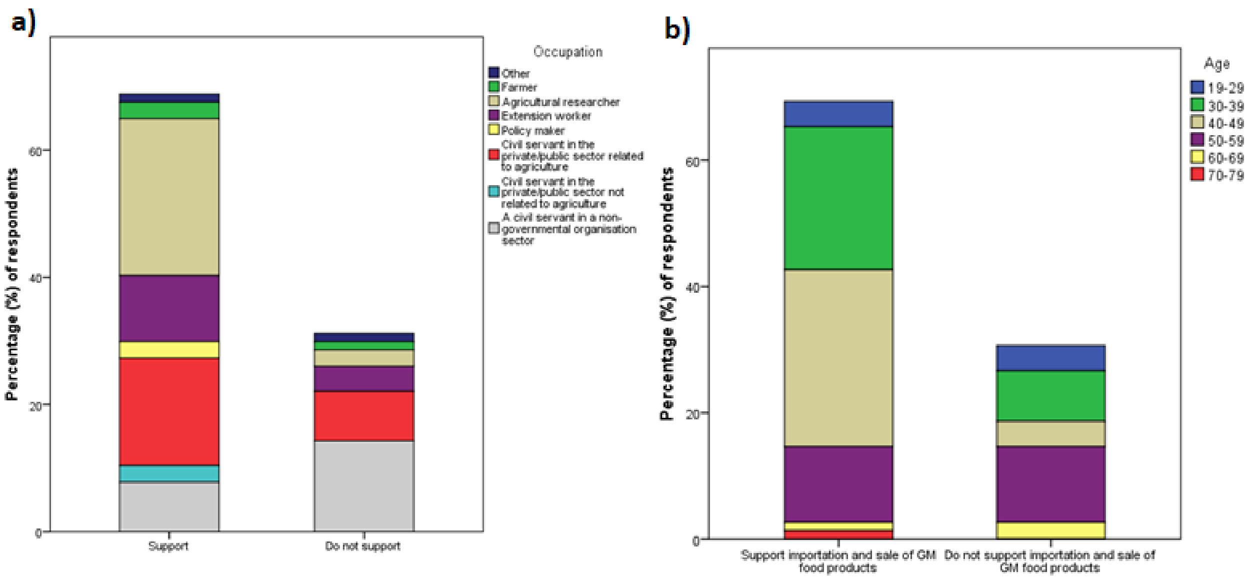


Figure E.5.13.7. Percentage (%) of Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders divided by a) occupation and b) age that supported importation and sale of genetically modified (GM) food products. Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative. **a)** There were significant differences in the level of support for importation and sale of GM food products on the basis of occupational group ($p<0.05$). **b)** There were significant differences in the level of support for importation and sale of GM food products on the basis of age ($p<0.05$). Response rate a-b: ~99 % (77 out of 78 participants).

Support importation and sale of food products with GM content [53]: other ~2% [1], farmer ~4% [2], agricultural researcher ~36% [19], extension worker ~15% [8], policy maker ~4% [2], civil servant (1) ~24% [13], civil servant (2) ~4% [2], civil servant (3) ~11% [6]; 19-29 ~6% [3], 30-39 ~32% [17], 40-49 ~40% [21], 50-59 ~17% [9], 60-69 ~2% [1], 70-79 ~2% [1], no specified age ~2% [1] (not shown in Fig. E.5.13.7**b)**. **Do not support importation and sale of food products with GM content [24]**: other ~4% [1], farmer ~4% [1], agricultural researcher ~8% [2], extension worker ~13% [3], civil servant (1) 25% [6], civil servant (3) ~46% [11]; 19-29 ~13% [3], 30-39 25% [6], 40-49 ~13% [3], 50-59 ~38% [9], 60-69 ~8% [2], no specified age ~4% [1] (not shown in Fig. E.5.13.7b). **No answer [1] (not shown in Fig. E.5.13.7):** civil servant (1) 100% [1]; 30-39 100% [1].

Table E.5.13. Attitudes and perceptions of consumption and labelling of food products with content from a genetically modified (GM) source among Kenyan, Ugandan, Tanzanian and Ethiopian stakeholders[1] divided by perception group (PG)[2]; in % and [number] of respondents.

		Total	Perception group (PG)
Do you pay attention to labels for food products as you buy food from the super markets?	Yes	64.1% [50]	PG1 34% [17], PG2 6% [3], PG3 24% [12], PG4 36% [18]
	No	35.9% [28]	PG1 ~4% [1], PG2 ~4% [1], PG3 ~ 27% [8], PG4 ~61% [17], no PG ~4% [1]
If you *do* pay attention to labels, do you check whether it has GMO content or not?[3]	Yes	49.2% [30]	PG1 50% [15], PG2 10% [3], PG3 ~17% [5], PG4 ~23% [7]
	No	20.8% [31]	PG1 ~10% [3], PG3 ~ 32% [10], PG4 ~58% [18]
Do you support for strict regulations and labelling of food products in your country?	Yes	75.6% [59]	PG1 ~27% [16], PG2 ~7% [4], PG3 ~29% [17], PG4 ~35% [21], no PG ~2% [1]
	No	23.1% [18]	PG1 ~11% [2], PG3 ~17% [3], PG4 ~72% [13]
Have you ever consumed food containing GMOs?	Yes	43.6% [34]	PG1 ~6% [2], PG2 ~ 6% [2], PG3 ~23% [8], PG4 ~65% [22]
	No	10.3% [8]	PG1 37.5% [3], PG3 25% [2], PG4 37.5% [3]
	I do not know	46.2% [36]	PG1 ~36% [13], PG2 ~6% [2], PG3 ~28% [10], PG4 ~ 28% [10], no PG ~3% [1]
If you have *not* consumed food containing GMOs, would you be willing to?[4]	Yes	68.7% [22]	PG1 ~18% [4], PG2 ~5% [1], PG3 ~27% [6], PG4 50% [11]
	No	31.3% [9]	PG1 ~89% [8], PG2 ~11% [1]

[1]Stakeholders include agricultural researchers, extension workers, policymakers, civil servants employed in the public/private sector related/not related to agriculture, civil servants employed in a non-governmental organisation, a biosafety regulatory expert, and a media representative.
[2]PG = perception group; 1 = negative towards GM crops, 2 = somewhat positive towards GM crops, 3 = positive towards GM crops, 4 = very positive towards GM crops.
[3]Expected number of respondents = 50, observed number of respondents = 61.
[4]Expected number of respondents = 44, observed number of respondents = 31.
Note: Total number of respondents = 78.
Note: Figures may not add to 100% due to rounding.

Appendix F. Statistical terms and equations

Table F.1. Statistical terms and equations.		
Statistical term	**Equation**	**Comments**
Chi squared value (χ^2)	$\sum \frac{(observed\ values - expected\ values)^2}{expected\ values}$	Measure of the relationship between two variables in a contingency table.
Correlation coefficient	$Z = \frac{cov(X,Y)}{\sigma X * \sigma Y}$	σ=standard deviation (see below); cov = covariance. Determines the level of association (i.e. strength and direction) between variables.
Covariance	$\frac{\sum(x-\bar{x})(y-\bar{y})}{n}$	The sum of deviations from the mean of x and y for each x,y data point.
Degrees of freedom, (Degr. fr) (df)	df = (rows-1)x(columns-1))	-
Logit transformation	logit(p) = log(p/1-p)	-
Standard deviation	$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}}$	Measure of the variation between samples (i.e the spread of values around the mean in a population).

Appendices 2. Lab Project

Appendix A. QIAprep® Spin Miniprep kit (Qiagen) – Procedure:

1) Pellet 1-5 ml of overnight bacterial culture by centrifugation at >8000 rpm (6800 x g) for 3 minutes at room temperature (15-25°C).
2) Re-suspend pelleted bacterial cells in 250 µl Buffer P1 and transfer to a centrifuge tube.
3) Add 250 µ of Buffer 2 and mix thoroughly until the solution becomes clear. OBS! Do not allow the lysis reaction to proceed for more than 5 minutes.
4) Add 350 µl Buffer N3 and mix immediately and thoroughly by inverting the tube 4-6 times.
5) Centrifuge for 10 minutes at 13000 rpm (~17900 x g) in a table-top microcentrifuge.
6) Apply the supernatant from step 5 to the QIAprep spin coloumn by decanting or pipetting. Centrifuge for 30-60 seconds and discard the flow-through.
7) If using endA+ strains or other bacterial strain with high nuclease activity or carbohydrate content, wash the QIAprep spin coloumn by adding 500 µl Buffer PB and centrifuge for 30-60 seconds. Discard the flow-through.
8) Wash the QIAprep spin coloumn by adding 750 µl Buffer PE. Centrifuge for 30-60 seconds and discard flow-through. Transfer the QIAprep spin coloumn to the collection tube. Centrifuge for 1 min to remove residual wash buffer.
9) Place the QIA prep coloumn in a clean 1.5 ml microcentrifuge tube. To elute DNA, add 50 µl Buffer EB (10 mM Tris-Cl, pH 8.5) or water to the center of the QIA prep coloumn, let it stand for 1 min, and centrifuge for 1 min.
10) If not used immediately, store in the fridge or freezer.

Appendix B. Making agarose gel for gel electrophoresis

Note: The amount of constituents will vary according to the amount of agarose gel being made.

- Making 0.5x TBE stock: Add 50 ml 10x TBE stock to glassware and top up with 1000 ml distilled water. Mix.
- To make 1 % agarose gel:

1) Add 1 g agarose to 100 ml of 0.5x TBE.
2) Heat in the microwave for 60-90 seconds until solution is clear. Let it cool.
3) Add 2.5 µl of gel red (Biotium) by pipetting.
4) Put the rack into the gel tray and pour the solution into the tray.
5) Let the gel set (>15 min).
6) Add the gel to the electrophoresis tray.
7) Add the same TBE buffer as used when making the gel, making sure to completely submerge the gel.
8) Remove comb.

Appendix C. β-glucuronidase (GUS) master mix

Preparing 10mM Tris, 50 mM NaCl:

1) Add 1.21 g Tris and 2.92 NaCl to 750 ml sterile distilled water (SDW).
2) Adjust pH to 7.2.
3) Make up volume to 1000 ml using SDW and autoclave for 15 minutes at 121°C.
4) Store at room temperature if not used immediately.

Preparing X-Gluc (10 mg/ml).

1) Dissolve 100 mg X-Gluc in 10 ml dimethylformamide (DM**F)***.
2) Store in 1 ml aliquots, wrap in foil** and store at -20°C.
3) X-gluc should not be thawed repeatedly. Avoid usage if colour has turned red-ish.

Note: DMF is toxic and mutagenic, thus gloves should be worn at all times. X-Gluc is extremely light-sensitive and needs to be wrapped in foil.

Preparing 10 % Triton X-100:

1) Add 5 ml Triton X-100 to 45 ml SDW and mix gently until dissolved.
2) Can be stored at room temperature.

Preparing GUS Master Mix:

GUS Master Mix (1 ml)	
Chemical	**Amount**
10mM Tris, 50 mM NaCl	890 µl
X-Gluc (stock 10 mg/ml)	100µl
10 % Triton X-100	10 µl

Protocol: Mix all constituents to create GUS mastermix. The total amount of staining buffer depends on the amount of samples investigated.

Note: After the mastermix has been created and added to the samples, avoid handling samples using metallic equipment (e.g. forceps) as this will cause a reaction to occur, making the buffer turn blue and giving false positives.

Appendix D. Vacuum infiltration and sonication

Method of vacuum infiltration:

1) Put the tubes containing the submerged explants in the vacuum infiltration chamber.
2) Turn on the generator and leave on for 5-10 minutes depending on the type of explant (e.g. 5 minutes for leaves, 10 minutes for tubers).
3) After 5-10 minutes, remove the hose to release the vacuum from the chamber.
4) Remove the lid and incubate the samples at 37˚C overnight.

Method of sonication:

1) Add water up to the indicated line of the sonication machine (failure to do so may cause tissue damag**e)**.
2) Add the tube(**a)** containing the sample to the water.
3) Set the temperature at the same level as the growth room (i.e. 25˚**C)**.
4) The recommended time is 1 minute (any longer may cause tissue damag**e)**.

Appendix E. Protocol for DNA extraction using DNeasy® Plant Minikit

Note: Kit can be stored at 15-25̊C for one year.

Before commencing extraction:

1) Perform all centrifugation steps at room temperature (15-25̊**C)** on the bench.
2) If necessary, re-dissolve any precipitates in Buffer AP1 and Buffer AW1 concentrater.
3) Add ethanol to buffer AW1 and buffer AW2 concentrates.
4) Preheat a water bath or heating block to 65̊C.

The Protocol:

1) Disrupt the samples ($\leq$100 mg wet weight or $\leq$20 mg lyophilized tissu**e)**.
2) Add 400 µl Buffer AP1 and 4 µl RNAse A. Vortex and incubate for 10 minutes at 65̊C. Invert the tubes 2-3 times during incubation. NB! Do not mix buffer AP1 and RNAse A before use.
3) Add 130 µl Buffer P3. Mix and incubate for 5 minutes on ice.
4) Recommended: **C**entrifuge the lysate for 5 minutes at 20 000 xg (14000 rpm).
5) Pipette the lysate into a QIA shredder spin column placed in a 2 ml collection tube. Centrifuge the lysate for 2 min at 20 000xg.
6) Transfer the flow-through into a new tube without disturbing the pellet (if present). Add 1.5 volumes of Buffer AW1 and mix by pipetting.
7) Transfer 650 µl of the mixture into a DNaesy Mini Spin column placed in a 2 ml collection tube. Let it bind to the column for 3-5 minutes before centrifuging.
8) Centrifuge for 1 minute at $\geq$6000 g ($\geq$8000 rpm). Discard the flow-through. Repeat this step with the remaining sample.
9) Place the spin column into a new 2 ml collection tube. Add 500 µl Buffer AW2 and centrifuge for 1 minute at $\geq$6000 xg. Discard the flow-through.
10) Add another 500 µl Buffer AW2. Centrifuge for 2 minutes at 20 000xg. NB: Remove the spin column from the collection tube carefully so that the column does not come into contact with the flow through.
11) Transfer the spin column to a new 1.5 ml or 2 ml centrifuge tube.

12) Add 100 µl Buffer AE for elution. Incubate for 5 minutes at room temperature (15-25°**C)**. Centrifuge for 1 minute at ≥6000 xg.
13) Repeat previous step.

Note: A total of 40 mg lyophilised tissue was used during the experiment, thus all volumes of the buffers and RNase were doubled.

Appendix F. Polymerase Chain Reaction (PCR) protocol

Protocol:

1) All of the components of the reaction mix are kept on ice and in the dark (wrapped in foil) as the enzymes and primers are light-sensitive.
2) Thaw and flick the tubes containing the components to make sure they are properly mixed.
3) Add the components to an Eppendorf tube by pipetting, starting with the largest volumes (i.e. first add H_2O, then the Buffer, then the primers, etc.) (see main thesis, Chapter 6, Table 6.1). Mix well.
4) To labelled PCR-tubes, add 20 µl of mastermix; for the positive control, add 23. 5 µl as the 'pure' plasmid DNA is highly concentrated.
5) Before commencing, flick the tubes containing the gDNA from the samples. Add 5 µl of template gDNA of each sample to its respective PCR tube containing the mastermix. For the positive control, add 1.5 µl of template DNA. Make sure to mix well when adding the gDNA to the mastermix.
6) Spin briefly to remove any air bubbles.
7) Place the samples in the PCR machine, and use empty PCR tubes to "buffer" the samples to avoid evaporation. Make sure the lids of the samples are properly closed.
8) Run the PCR (see main thesis, Chapter 6, Table 6.2).

Appendix G. Sub-culturing and observations of embryogenic cells of banana cultivars ‘Cavendish Williams’ and ‘Sukali Ndiizi’

Note: Only a selected number of images have been included in an attempt to limit the number of pages. Unfortunately, images of control were not included until later stages in some cases.

G.1. Transformation experiment 1: Sub-culturing and observation of embryogenic cells of ‘Cavendish Williams’ transformed using β-glucuronidase (*gusA)* and green fluorescent protein gene (*gfp*)

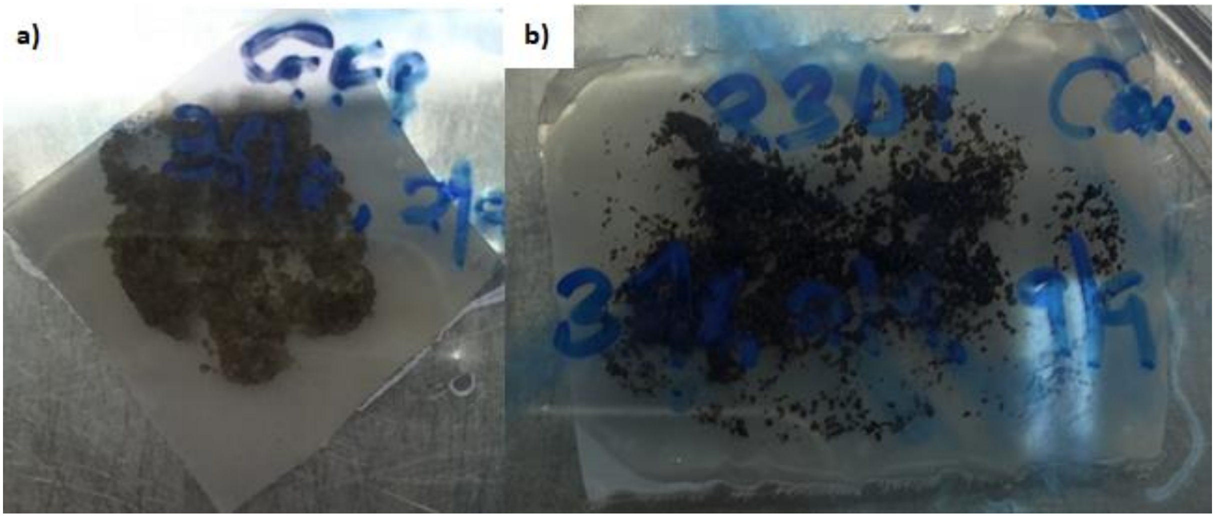


Figure G.1.1. Embryogenic cells of banana cultivar ‘Cavendish Williams’ transformed with a) green fluorescent protein gene (*gfp*) and b) β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (MA3) with selection 25 days after transformation. a) Growth and appearance of a few embryos is evident (difficult to deduce due to poor image quality). **b)** No embryos present.

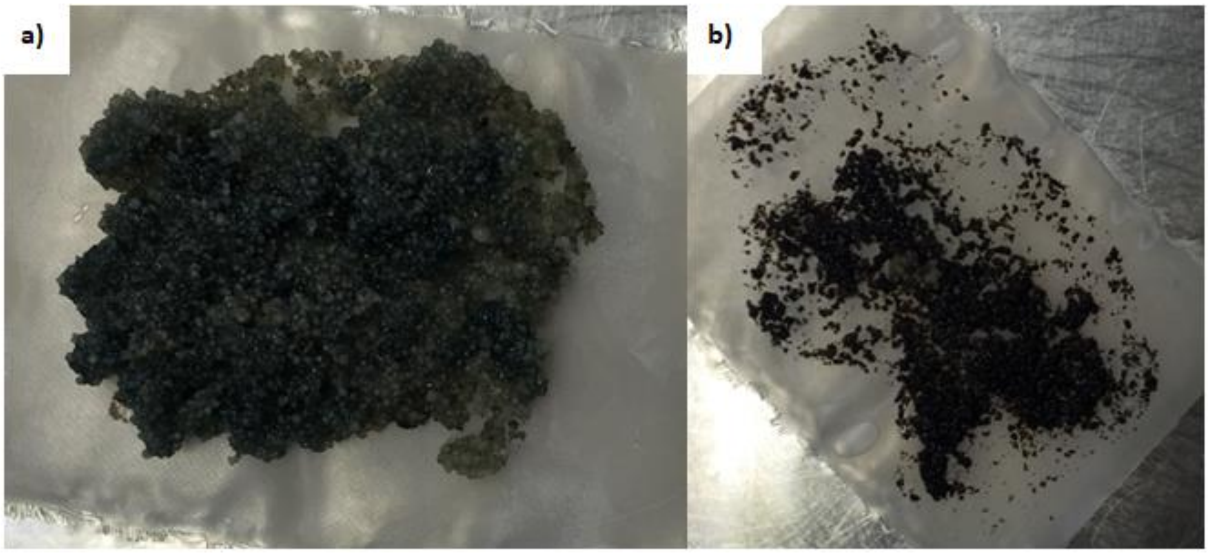


Figure G.1.2. Embryogenic cells of banana cultivar ‘Cavendish Williams’ transformed with a) green fluorescent protein gene (*gfp*) and b) β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (MA3) with selection 38 days after transformation. a) Several white-ish embryos have started to appear. **b)** A few embryos have started to appear.

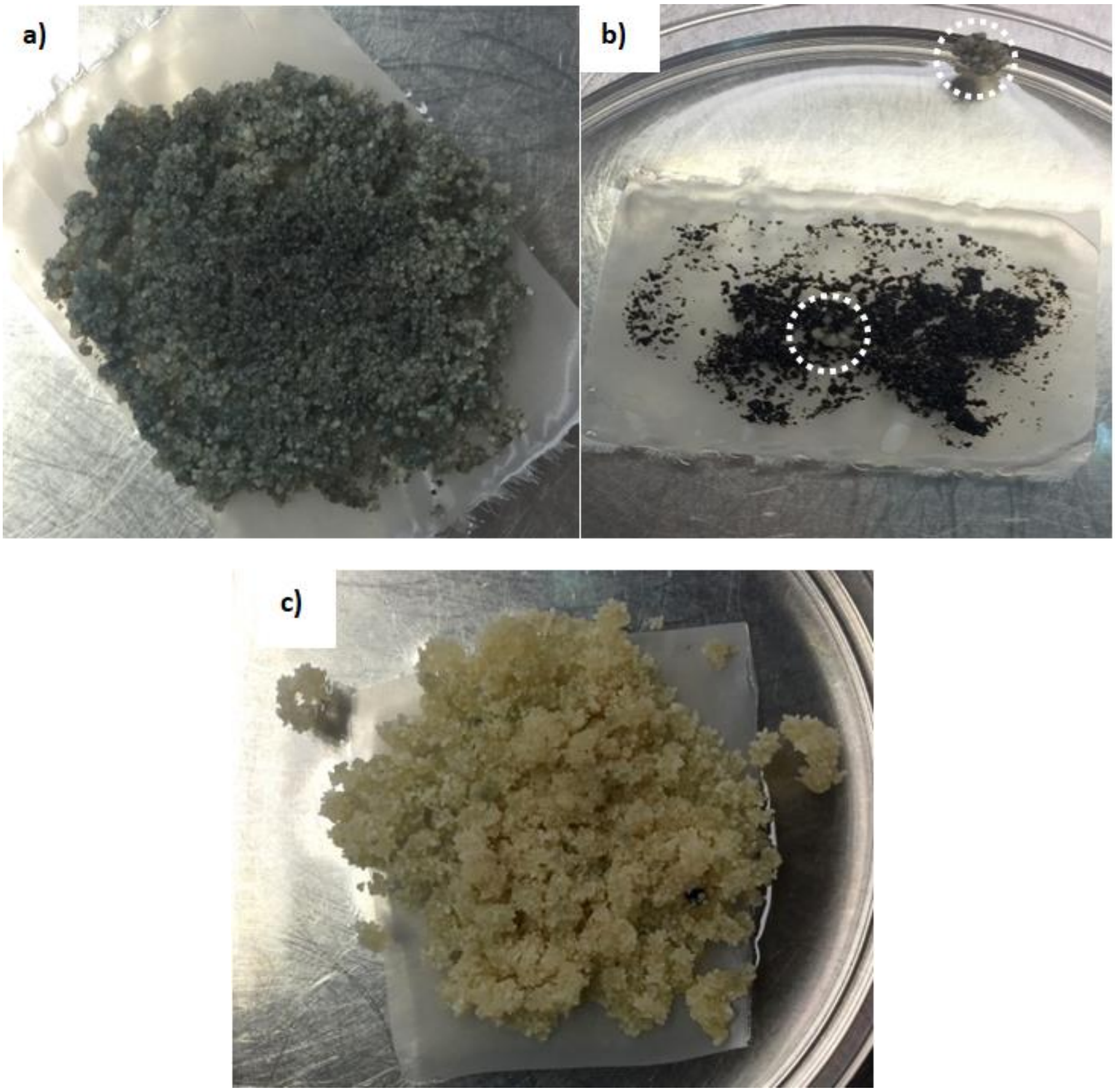


Figure G.1.3. Embryogenic cells of banana cultivar 'Cavendish Williams' transformed with a) green fluorescent protein gene (*gfp*) and b) β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (MA3) with selection 50 days after transformation. c) Embryogenic cells of non-transgenic (negative control) of 'Cavendish Williams' cultivated on MA3 without selection. Several embryos have started to appear in **a)** and **c)**, while comparably fewer embryos have started to appear in **b)** (indicated by dashed circles).

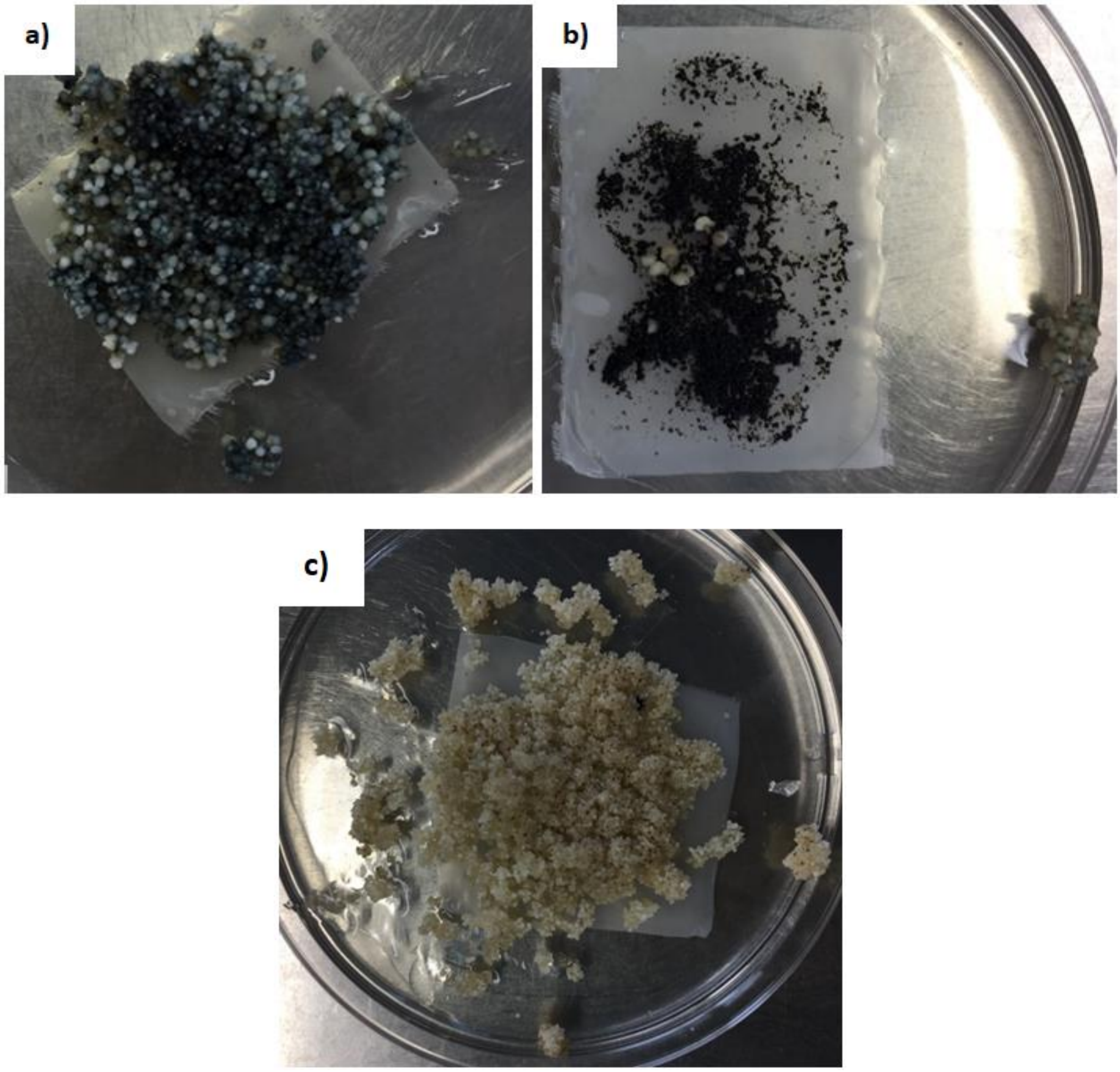


Figure G.1.4. Embryogenic cells of banana cultivar 'Cavendish Williams' transformed with a) green fluorescent protein gene (*gfp*) and b) β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (MA3) with selection 63 days after transformation. c) Embryogenic cells of non-transgenic (negative control) of 'Cavendish Williams' cultivated on MA3 without selection. Embryos were picked and transferred onto Embryo Maturation Medium (RD1) with/without selection at this point and onwards.

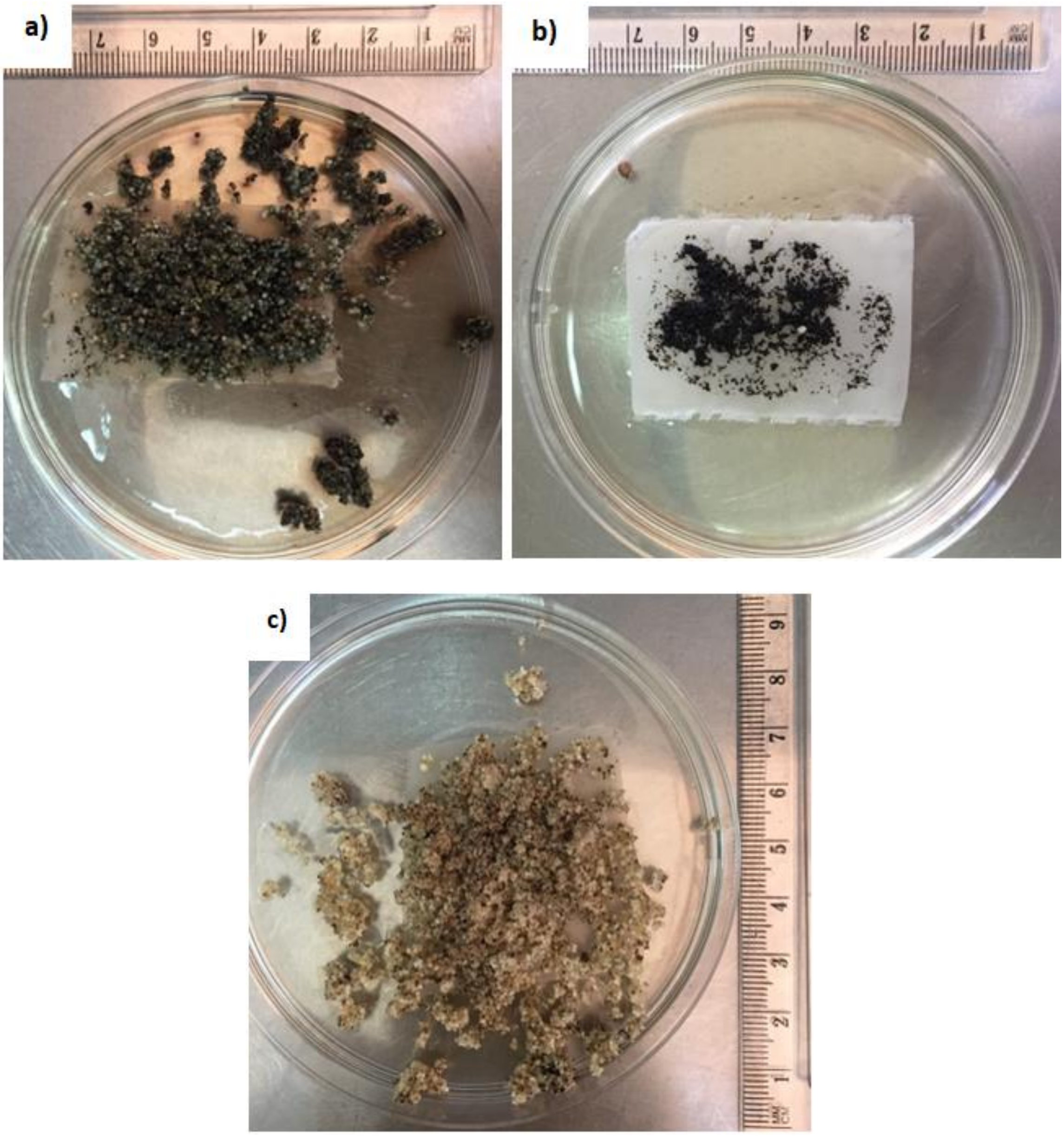


Figure G.1.5. Embryogenic cells of banana cultivar 'Cavendish Williams' transformed with a) green fluorescent protein gene (*gfp*) and b) β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (MA3) with selection 92 days after transformation. c) Embryogenic cells of non-transgenic (negative control) of 'Cavendish Williams' cultivated on MA3 without selection. Embryos still present (only a single embryo in **b)**, but blackening due to cell death and/or build-up of phenols is apparent.

G.2. Transformation experiment 2: Sub-culturing and observation of embryogenic cells of 'Cavendish Williams' and 'Sukali Ndizii' transformed using β-glucuronidase (*gusA)* and green fluorescent protein gene (*gfp*)

Note: Unfortunately, Cavendish Williams transformed using both *gusA* and *gfp* were discarded on the 01.11.16 due to necrosis and no apparent growth of embryos. Consequently, images are only included for the first and final day of sub-culturing.

G.2.1. 'Cavendish Williams' and 'Sukali Ndiizi' transformed with β-glucuronidase (gusA)

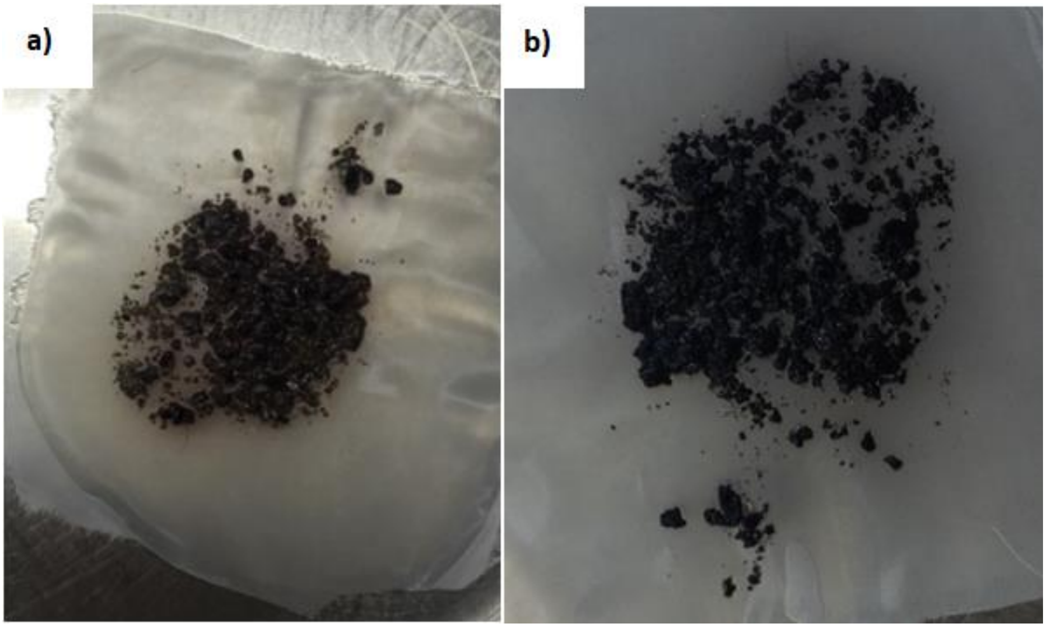


Figure G.2.1.1. Embryogenic cells of banana cultivar 'Cavendish Williams' cultivated on Embryo Development Medium (MA3) with selection a) 11 and b) 53 days after transformation with β-glucuronidase (*gusA)*. Necrosis (browning and blackening) was present and no growth of embryos observed, thus plates were discarded on the 01.11.16.

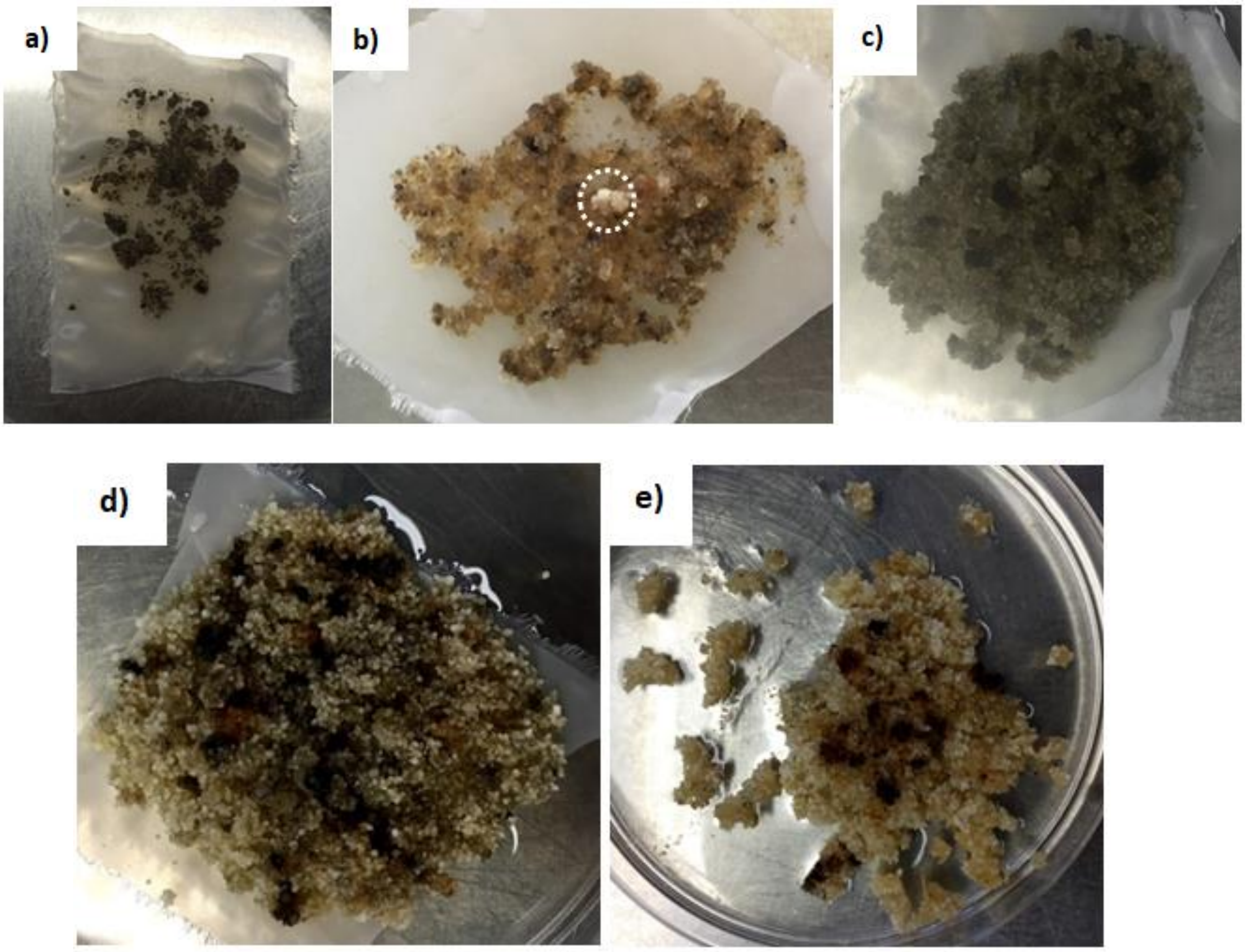


Figure G.2.1.2. Embryogenic cells of banana cultivar 'Sukali Ndiizi' cultivated on Embryo Development Medium (MA3) with selection a) 11, b) 25, c) 39 and d) 53 days after transformation with β-glucuronidase (*gusA)*. e) Embryogenic cells of non-transgenic (negative control) 'Sukali Ndiizi' cultivated on MA3 without selection 53 days after initiation of transformation experiment. b-e) White-ish embryos started to appear approximately 25 days after transformation. Embryos were picked for transfer to Embryo Maturation Medium (RD1) with/without selection approximately 53 days after transformation and onwards. Blackening indicates cell death and/or presence of phenols.

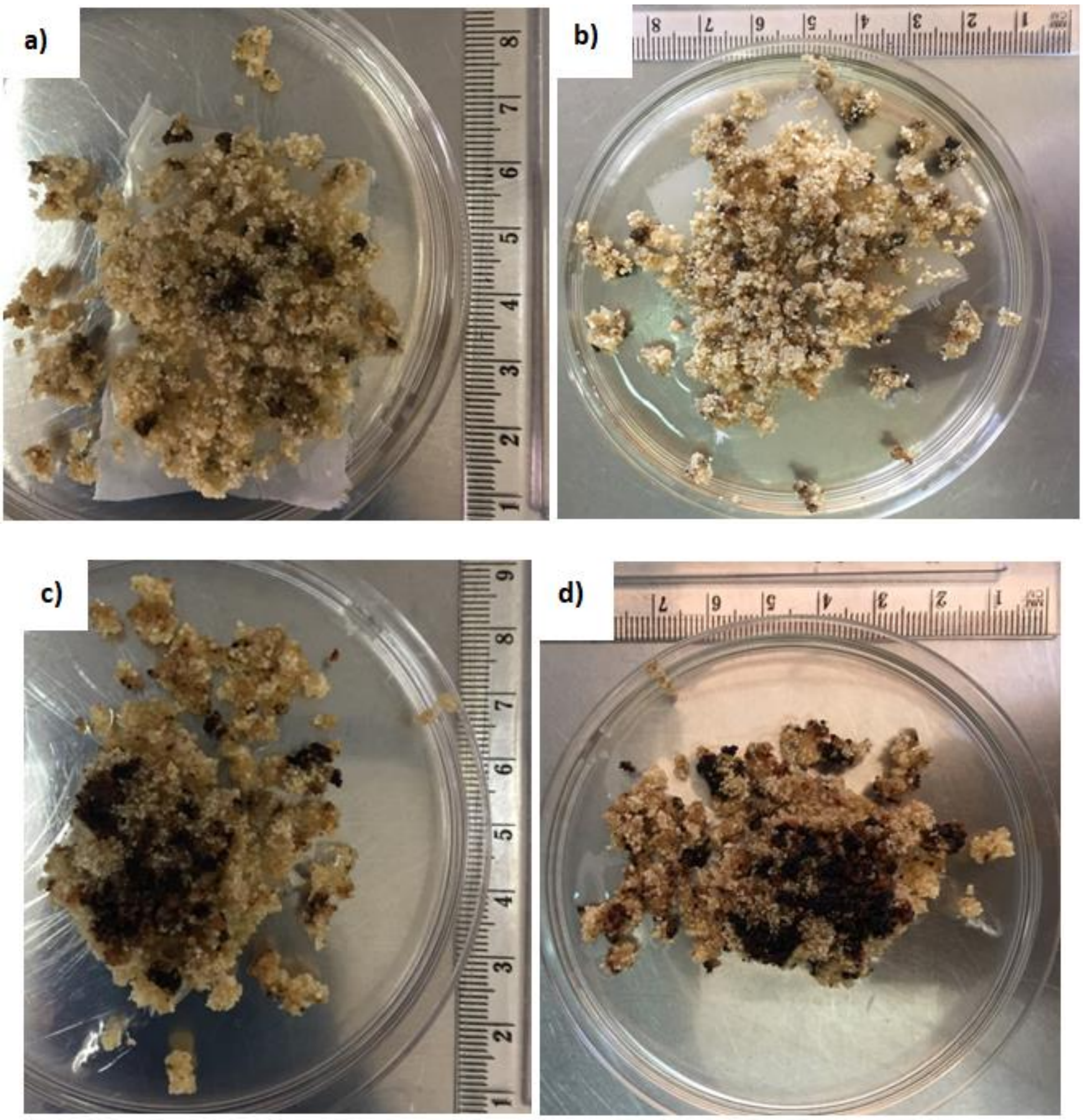


Figure G.2.1.3. Embryogenic cells of banana cultivar 'Sukali Ndiizi' cultivated on Embryo Development Medium (MA3) with selection a) 65 and b) 82 days after transformation with β-glucuronidase (*gusA*). Embryogenic cells of non-transgenic (negative control) 'Sukali Ndiizi' cultivated on MA3 without selection c) 65 and d) 82 days after initiation of transformation experiment. a-d) Embryos present, but blackening due to cell death and/or build-up of phenols is apparent.

G.2.2. 'Cavendish Williams' and 'Sukali Ndiizi' transformed with green fluorescent protein gene (gfp)

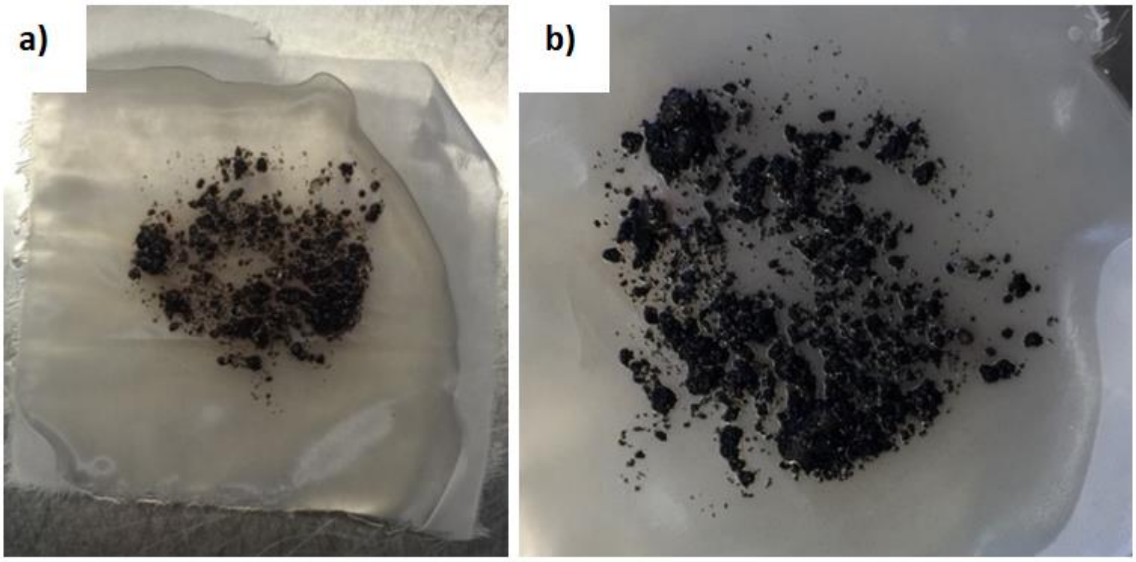


Figure G.2.2.1. Embryogenic cells of banana cultivar 'Cavendish Williams' cultivated on Embryog Maturation Medium (MA3) with selection a) 11 days and b) 53 days after transformation with green fluorescent protein gene (*gfp*). Necrosis (browning and blackening) was present and no growth of embryos observed, thus the plates were discarded on the 01.11.16.

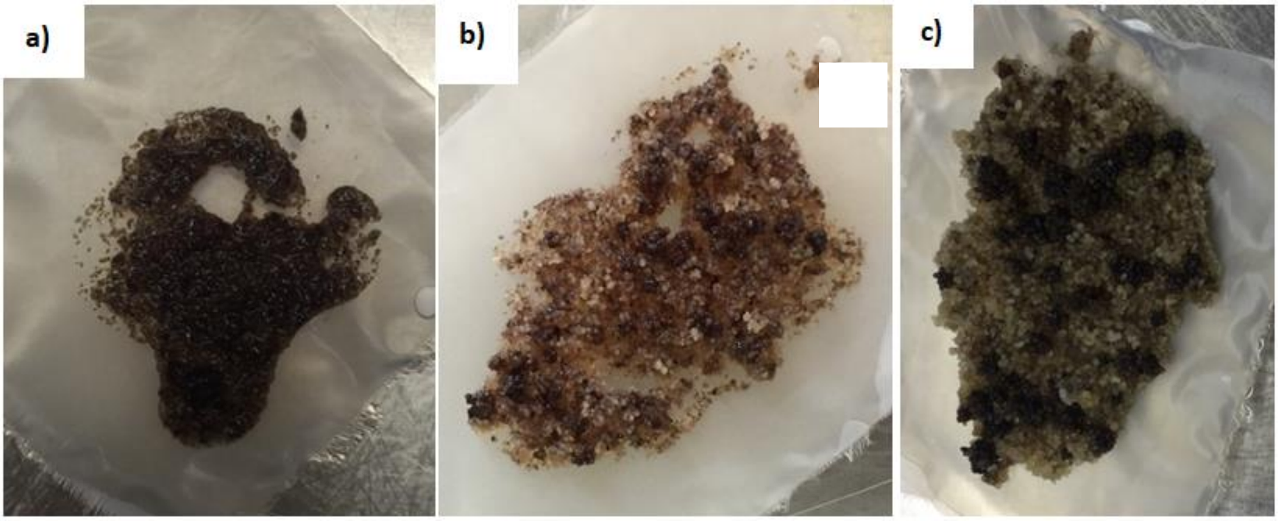


Figure G.2.2.2. Embryogenic cells of banana cultivar 'Sukali Ndiizi' cultivated on Embryo Maturation Medium (MA3) with selection a) 11, b) 25 and c) 39 days after transformation with green fluorescent protein gene (*gfp*). White-ish embryos started to appear approximately 25 days after transformation.

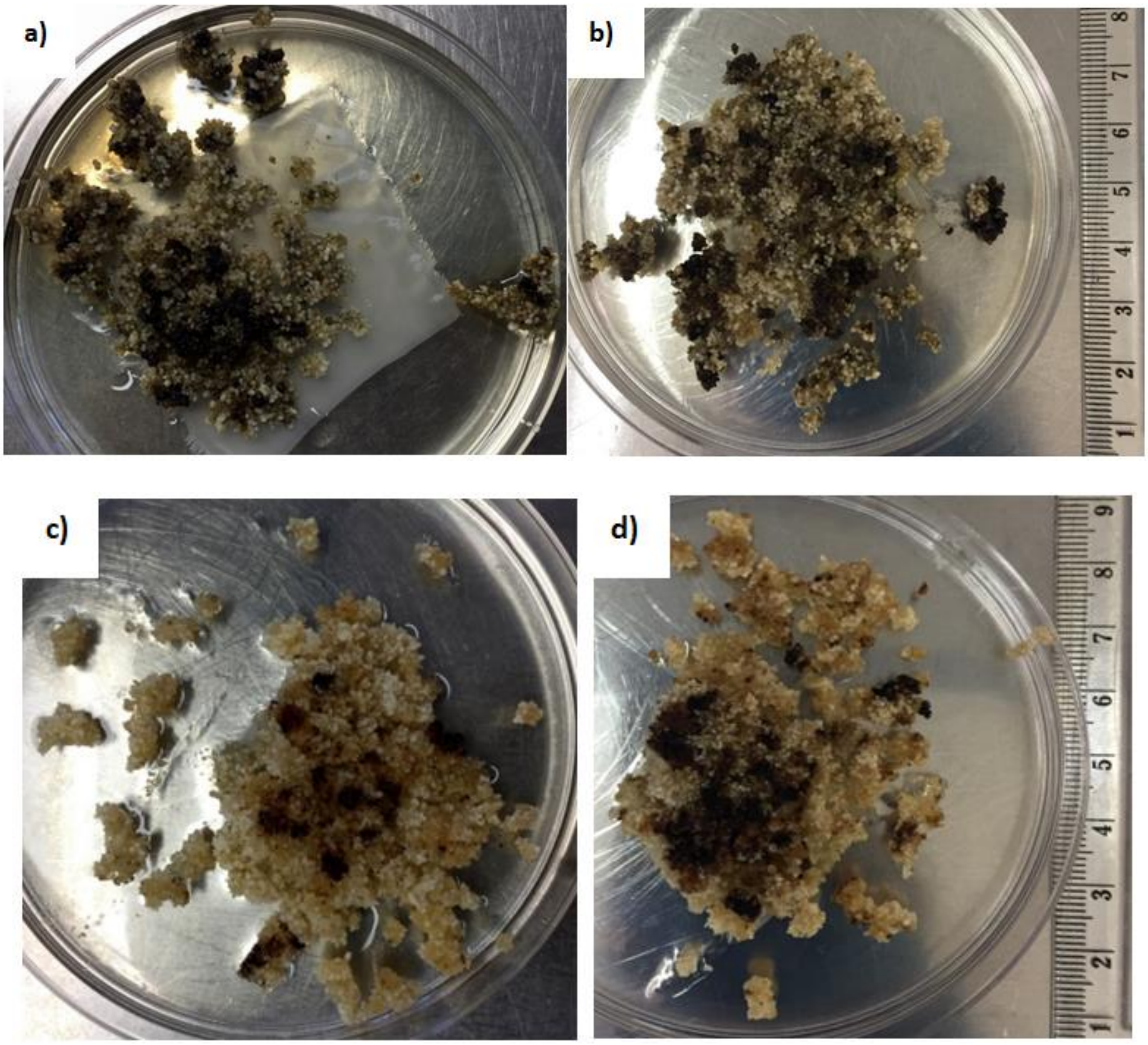


Figure G.2.2.3. Embryogenic cells of banana cultivar 'Sukali Ndiizi' cultivated on Embryo Maturation Medium (MA3) with selection a) 53 and b) 65 days after transformation with green fluorescent protein gene (*gfp*). Embryogenic cells of non-transgenic (negative control) of 'Sukali Ndiizi' cultivated on MA3 without selection c) 53 and d) 65 days after initiation of transformation experiment. a-**d)** Embryos were picked for transfer to Embryo Maturation Medium (RD1) with/without selection from approximately day 53 and onwards. Blackening indicates cell death and/or build-up of phenols.

Appendix H. Picking embryos for transfer from Embryo Development Media (MA3) to Embryo Maturation Media (RD1); Picking and transfer of embryos from RD1 to RD2 and Maturation Media (MA4)

H.1. Picking of single embryos from embryogenic cell cultures of banana cultivar 'Cavendish Williams' (1st transformation experiment)

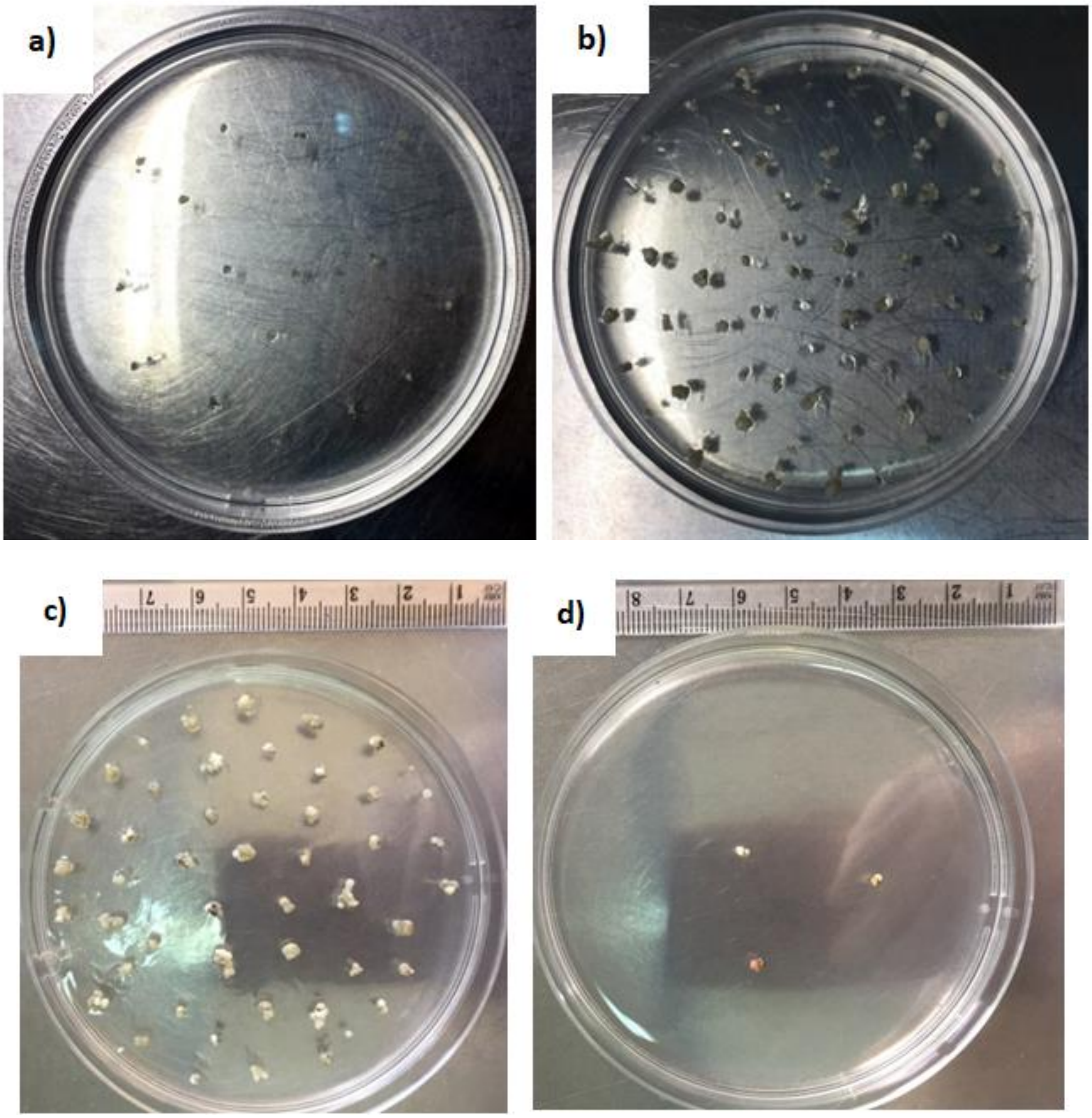


Figure H.1.1. a) Single embryos of banana cultivar 'Cavendish Williams' transformed with green fluorescent protein gene (*gfp*) cultivated on Embryo Development Medium (RD1) with selection 63 days after transformation. b) Single embryos transferred to RD2 (1 mg/l BAP) with selection after one month on RD1 with selection. c) Single and clustered embryos transferred to Germination Medium (MA4) (1 mg/ml IAA, 1 mg/ml BAP) with selection after one month on RD1 with selection. d) Single embryos of banana cultivar 'Cavendish Williams' transformed with β-glucuronidase (*gusA)* cultivated on Embryo Development Medium (RD1) with selection 63 days after transformation.

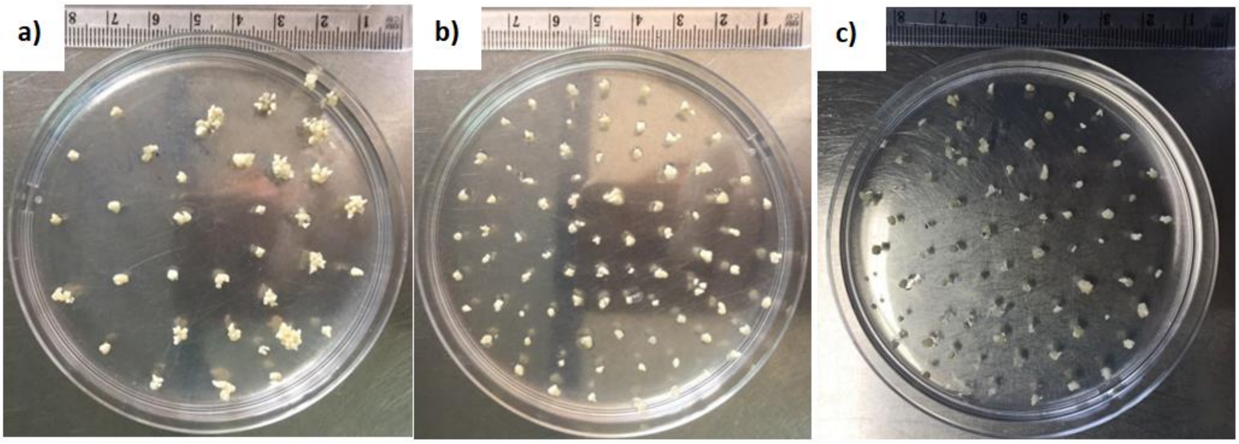


Figure H.1.2. a) Single and clustered embryos of non-transformed (negative control) banana cultivar 'Cavendish Williams' after one month on Embryo Development Medium (RD1) without selection (92 days after initiation of transformation experiment). b) Single embryos of non-transformed (negative control) banana cultivar 'Cavendish Williams' after picking from RD1 without selection and transfer to RD2 (1 mg/ml BAP) without selection. c) Single embryos of non-transformed (negative control) banana cultivar 'Cavendish Williams' after picking from RD1 and transfer to Embryo Maturation Medium (MA4) (1 mg/ml IAA, 1 mg/ml BAP) without selection.

H.2. Picking of single embryos from embryogenic cell cultures of banana cultivar 'Sukali Ndiizi' (2nd transformation experiment)

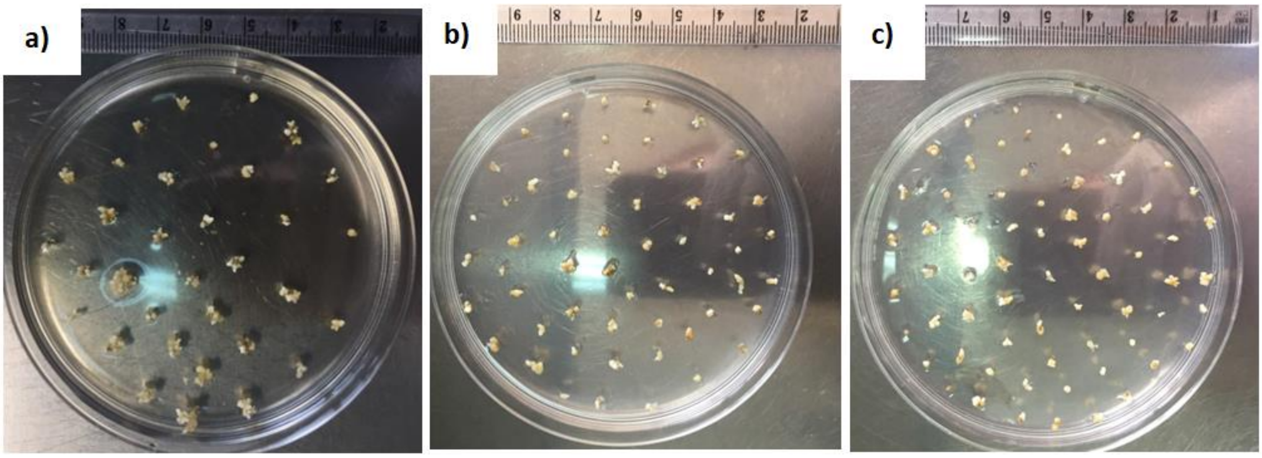


Figure H.2.1. a) Single embryos of banana cultivar 'Sukali Ndiizi' transformed with β-glucuronidase (*gusA)* after one month on Embryo Development Medium (RD1) with selection (82 days after transformation). b) Picking and transfer of single embryos from RD1 and transfer to RD2 (1mg/ml BAP) with selection. c) Picking and transfer of single embryos from RD1 to Embryo Maturation Medium (MA4) (1 mg/ml IAA, 1 mg/ml BAP).

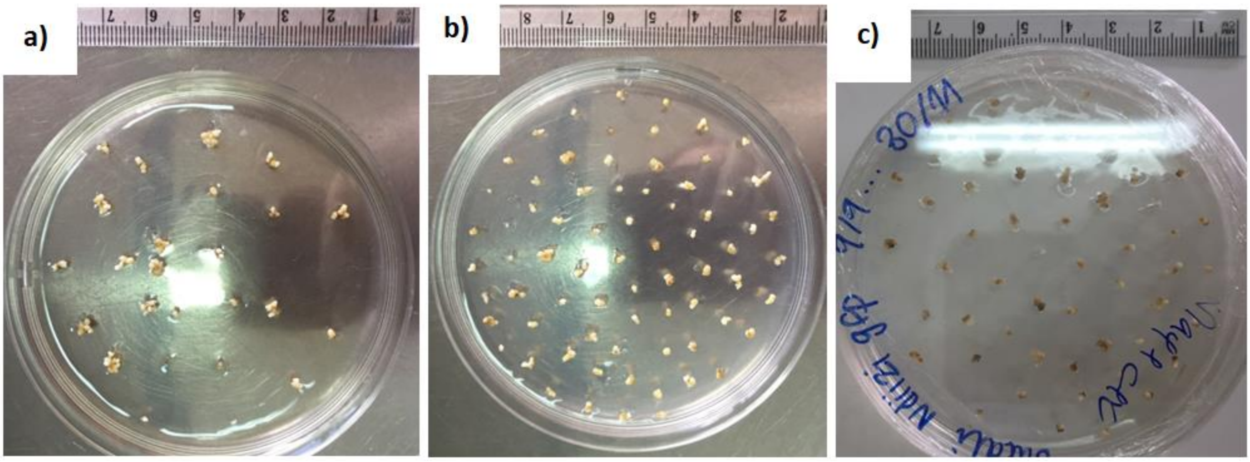


Figure H.2.2. a) Single embryos of banana cultivar 'Sukali Ndiizi' transformed with green fluorescent protein gene (*gfp*) after one month on Embryo Development Medium (RD1) with selection (82 days after transformation). b) Picking and transfer of single embryos from RD1 and transfer to RD2 (1mg/ml BAP) with selection. c) Picking and transfer of single embryos from RD1 to Embryo Maturation Medium (MA4) (1 mg/ml IAA, 1 mg/ml BAP).

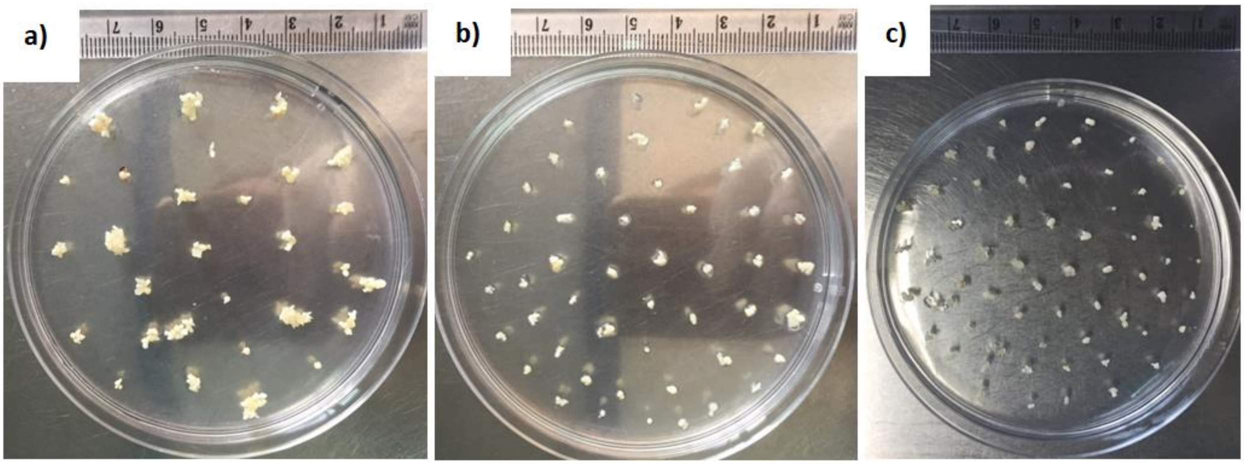


Figure H.2.3. a) Single and clustered embryos of non-transformed (negative control) banana cultivar 'Sukali Ndiizi' after one month on Embryo Development Medium (RD1) without selection (92 days after initiation of transformation experiment). B) Single embryos of non-transformed (negative control) banana cultivar 'Sukali Ndiizi' after picking from RD1 without selection and transfer to RD2 (1 mg/ml BAP) without selection. c) Single embryos of non-transformed (negative control) banana cultivar 'Sukali Ndiizi' after picking from RD1 and transfer to Embryo Maturation Medium (MA4) (1 mg/ml IAA, 1 mg/ml BAP) without selection.

Appendix I. Media for banana tissue culture and transformation

List provided by Dr. Jaindra Tripathi, International Institute of Tropical Agriculture (IIT**A)**, Kenya.

I.1. Composition of MS medium (Murashige and Skoog, 1962)

Constituents	**MS Medium (mg/l)**	
Stock I (Macronutrients)		**10X (gm\l)**
NH_4NO_3	1650	16.5
KNO_3	1900	19.0
$CaCl_2.2H_2O$	440	4.4
$MgSO_4.7H_2O$	370	3.7
KH_2PO_4	170	1.7
Stock II (Micronutrients)		**100X (gm/l)**
KI	0.83	0.083
H_3BO_3	6.2	0.62
$MnSO_4.4H_2O$	22.3	2.23
$ZnSO_4.7H_2O$	8.6	0.86
$Na_2MoO_4.2H_2O$	0.25	0.025
$CuSO_4.5H_2O$	0.025	0.0025
$CoCl_2.6H_2O$	0.025	0.0025
Stock III (Iron)		**100X (gm/l)**
$Na_2EDTA.2H_2O$	37.3	3.73
$FeSO_4.7H_2O$	27.8	2.78
Stock IV (Vitamins + Inositol)		**200X (gm/l)**
Nicotinic Acid	0.5	0.1
Pyridoxine. HCl	0.5	0.1
Thiamine. HCl	1	0.2
Glycine	2.0	0.4
Myo-Inositol	100	20
Stock V (Antioxidant)		**gm/10 ml**
Ascorbic Acid	10 mg/ml	0.1

I.2. Composition of Morel Vitamins (Morel and Wetmore, 1951)

Components	Final concentration (mg/l)	200X (500 ml)
Biotine (1mg/ml)	0.01	1 ml
Calcium panthotenate	1	100 mg
Myo-inositol	100	10 g
Nicotinic Acid	1	100 mg
Pyridoxine HCl	1	100 mg
Thiamine HCl	1	100 mg

I.3. Preparation and storage of growth regulator solution

Growth regulators	Stock Solution	Solvent	Solution storage	Sterilization
Auxins				
2,4-D	1 mg/l	EtoH/1N NaOH	0-5^{o}C	CA/F
2,4,5-T	1 mg/l	EtoH/1N NaOH	0^{o}C	CA/F
IBA	1 mg/l	EtoH/1N NaOH	0^{o}C	CA/F
NAA	1 mg/l	1N NaOH	0-5^{o}C	CA
IAA	1 mg/l	1N NaOH	0^{o}C	F
Cytokinins				
BAP	1 mg/l	1N NaOH	0-5^{o}C	CA
KIN	1 mg/l	1N NaOH	0^{o}C	CA/F
TDZ	1 mg/l	1N NaOH	0^{o}C	CA/F
ZET	1 mg/l	1N NaOH	0^{o}C	CA/F

CA- coautoclavable with other media components; CA/F- coautoclavable with other media components, however, some loss of activity may occur. Therefore, filter sterilization was performed in critical experiments; F- filter sterilization (0.22 m).

I.4. Composition of Proliferation Medium (PM) using stock solutions

Proliferation media	**1 L**	**500 ml**
Macros (10X)	100 ml	50 ml
Micros (100X)	10 ml	5 ml
Fe^{3+} (100X)	10 ml	5 ml
Vitamins (200X)	5 ml	2.5 ml
Sucrose	30 g	15 g
Ascorbic acid (10mg/ml)	1 ml	0.5 ml
BAP (1mg/ml)	5 ml	2.5 ml
Gelrite	2.4 g	1.2 g
pH 5.8		

I.5. Composition of Proliferation Medium (PM) using MS premix

Proliferation media	**1 L**	**500 ml**
MS salts + Vitamins Premix	4.4 g	2.2 g
Sucrose	30 g	15 g
Ascorbic acid (10 mg/ml)	1 ml	0.5 ml
BAP (1 mg/ml)	5 ml	2.5 ml
Gelrite	2.4 g	1.2 g
pH 5.8		

Note: MS salt premix (Duchefa, M0222) contains MS salts, vitamins, iron and myo-inositol.

I.6. Composition of Rooting Medium (RM)

Proliferation media	**1 L**	**500 ml**
MS salts + Vitamins Premix	4.4 g	2.2 g
Sucrose	30 g	15 g
Ascorbic acid (10 mg/ml)	1 ml	0.5 ml
IBA (1 mg/ml)	1 ml	0.5 ml
Gelrite	2.4 g	1.2 g
pH 5.8		

I.7. Multiple Bud Induction Medium (MBI or modified P4)

Stock	Final concentration	500 ml	1 L
MS salts + Vitamins + myo-inositol Premix		2.2 g	4.4 g
Ascorbic acid (10 mg/ml)	10 mg/l	0.5 ml	1 ml
IAA (1 mg/ml)	0.175 mg/l	88 µl	175 µl
BAP (1 mg/ml)	22 mg/l	11.3 ml	22.7 ml
Sucrose	30 g/l	15 g	30 g
Gelrite	3 g/l	1.5 g	3 g
pH 5.8			

I.8. Callus Induction Medium (CIM or ZZs)

Composition	Working concentration	1 L	500 ml
Macros (10X)	½	50 ml	25 ml
Micros (100X)		10 ml	5 ml
Iron (100X)		10 ml	5 ml
Vitamins + myo-inositol (200X)		5 ml	2.5 ml
Ascorbic acid (10 mg/ml)		1 ml	500 µl
2,4-D (1 mg/ml)		1 ml	500 µl
Zeatin (1 mg/ml)	0.219 mg/l	219 µl	210 µl
Sucrose	30 g/l	30 g	15 g
Gelrite	3 g/l	3 g	1.5 g
pH 5.8			

Note: For preparing ZZ liquid medium, do not add gelrite.

I.9. Embryo Development Medium (EDM – Modified MA3)

Components	Working concentration	1 L
SH salts premix	3.2 g	3.2 g
MS Vitamins (200X)	1X	5 ml
Glutamine	100 mg/l	100 mg
Malt extract	100 mg/l	100 mg
Biotin (1 mg/ml)	1 mg/l	1 ml
Proline	230 mg/l	230 mg
Citric acid	60 mg/l	60 mg
Ascorbic acid (10 mg/ml)	60 mg/l	6 ml
Cysteine	400 mg/l	400 mg
NAA (1 mg/ml)	0.2 mg/l	200 µl
2 iP (1 mg/ml)	0.2 mg/l	200 µl
Kinetin (1 mg/ml)	0.2 mg/l	200 µl
Zeatin (1 mg/ml)*	0.1 mg/l	100 µl
Lactose	10 g/l	10 g
Sucrose	45 g/l	45 g
Gelrite	3 g/l	3 g
pH 5.8		

*Zeatin should be filter sterilized and add after autoclaving, when the temperature of the medium has come down to 50^0c. Schenk & Hildebrandt (SH) Basal salt medium-Premix (Duchefa, S0225).

I.10. Embryo Maturation Medium (EMM/ RD1)

Composition	Working concentration	1 L	500 ml
Macros (10X)	½	50 ml	25 ml
Micros (100X)		10 ml	5 ml
Iron (100X)		10 ml	5 ml
Vitamins (200X)		5 ml	2.5 ml
Ascorbic acid (10 mg/ml)		1 ml	500 µl
Sucrose	30 g/l	30 g	15 g
Gelrite	3 g/l	3 g	1.5 g
pH 5.8			

I.11. Germination Medium (GM/ MA4)

Composition	Working concentration	1 L
Macros (10X)	1X	100 ml
Micros (100X)	1X	10 ml
Iron (100X)	1X	10 ml
Moral Vitamins (200X)	1X	5 ml
IAA (1 mg/ml)	2 mg/l	2 ml
BAP (1 mg/ml)	0.05 mg/l	500 µl
Sucrose	30 g/l	30 g
Gelrite	3 g/l	3 g
pH 5.8		

I.12. RD2 Medium

Composition	Working concentration	1 L	500 ml
Macros (10X)	½	50 ml	25 ml
Micros (100X)		10 ml	5 ml
Iron (100X)		10 ml	5 ml
Vitamins (200X)		5 ml	2.5 ml
Ascorbic acid (10 mg/ml)		1 ml	500 µl
BAP (1 mg/l)	0.25 mg/l	250 µl	125 µl
Sucrose	30 g/l	30 g	15 g
Gelrite	3 g/l	3 g	1.5 g
pH 5.8			

I.13. MA1 Medium for callus induction using flower

Components	Working concentration	1 L
MS salts + vitamins premix (Duchefa, M0222)	4.4 g	4.4 g
Biotin (1 mg/ml)	1 mg/l	1 ml
IAA (1 mg/ml)	1 mg/l	1 ml
2,4-D (1 mg/ml)	4 mg/l	4 ml
NAA (1 mg/ml)	1 mg/l	1 ml
Sucrose	30 g/l	30 g
Gelrite	3 g/l	3 g
pH 5.7		

I.14. MA2 Medium

Components	Working concentration	1 L
MS salts + vitamins premix (Duchefa, M0222)	4.4 g	4.4 g
Glutamine	100 mg/l	100 mg
Malt extract	100 mg/l	100 mg
Biotin (1mg/ml)	1 mg/l	1 ml
2,4-D (1 mg/ml)	1 mg/l	1 ml
Sucrose	45 g/l	45 g
pH 5.3		

I.15. Bacterial Co-Culture Medium (BCCM- A+B): 500 ml

BCCM (A): 300 ml – filter sterilize

Components	Stock	Amount for 300 ml
Sucrose		15 g
Maltose		15 g
Glucose		5 g
L-Glutamine		50 mg
Malt extract		50 mg
Proline		150 mg
L-Cystein		200 mg
MS vitamins + myo-inositol	200X	5 ml
Ascorbic acid	10 mg/ml	500 µl
Biotin	1 mg/ ml	500 µl
Acetosyringone	400 mM	400 µl
Bring volume to 300 ml, pH 5.3, filter sterilize & dispense 30 ml aliquots in falcon tubes & store at -20^{0}C		

Note: For preparing acetosyringone (400mM) stock, dissolve 78.4 mg per ml DMSO and filter sterilize. Store at -20^{0}C.

BCCM (B): 200 ml: Autoclave

Components (MS)	Amount for 200 ml
Macro (10X)	5 ml
Micro (100X)	5 ml
Iron (100)	5 ml
Gelrite	5 g
pH 5.5	
Thaw A (30 ml), melt B (20 ml), mix & pour 10 ml in 60 mm plates	

I.16. Bacterial Re-Suspension Medium (BRM)

BRM-A: Autoclavable

Components (MS)	Amount used per 500 ml
Macro (10X)	6.25 ml
Micro (100X)	6.25 ml
Iron (100X)	6.25 ml
MS Vitamins (200X)	2.5 ml
Sucrose	42.75 g
Top up to 500 ml, pH 5.3, make aliquots of 100 ml, autoclave and store at 4°C	

BRM-B: Filter sterilize

Components (MS)	Stock	Amount used in 125 ml
Thiamine	10 mg/ml	5.63 mg
Cystein		250 mg
Glucose		22.5 g
Acetosyringone	400 mM Dissolve 78.4 mg per ml DMSO	312.5 µl
Top up to 125 ml, pH 5.3, filter sterilize, make aliquots of 25 ml and store at -20°C		

Mix 100 ml of BRM-A and 25 ml of BRM-B and use for preparation of *Agrobacterium* suspension for co-cultivation.

I.17. LB Medium

Components	Amount
Tryptone	10g/l
Yeast extract	5g/l
Micro agar	10 g/l (LB agar only)

Appendices 3. Other

Appendix A. Guidelines for socio-economic impact assessment set by the Kenyan National Biosafety Authority (NBA)

Concept/subject	Elements to consider
Food security and/or technology sustainability	Will there be increase in yield /ha? Will there be surplus for individuals / country by growing the transgenic crop? Will the technology be continuous? Will the new technology complement other income sources?
Access to the Technology	Will other technologies be available to guarantee freedom of choice? Will socioeconomic impact assessment increase time and cost of regulatory approvals hence delaying its adoption? Gender issues: Accessibility of the proposed GM technology to women versus men.
Income to farmers	Will farmers make more money using the new GM technology compared to the *status quo*? After cost-benefit analysis, is the new technology expected to be beneficial to farmers?
Cost of seeds and other inputs	Are seeds & other farm inputs affordable to ordinary farmers? Does the technology reduce cost of production? Are there economies of scale?
Co-existence	How to ensure genetic integrity between the transgenic crop vis a vis organic & conventional plants (Gypsophila)? How will you deal with litigation(s) if any in case of disputes arising from co-existence?
Benefits and Freedom of choice	Any tangible benefits to consumer eg. Reduced commodity prices, enhanced nutritional composition? Is the society healthier? Is there good labelling practices? Can consumers easily access conventional or organic products of the crop you intend to transform and release into the environment?
Biosafety & Stewardship	What happens if adverse effects are detected later when the product is in the market and people/animals have consumed the GMO? Will farmers be trained & follow laid down Good Agricultural Practices (GAPs)

Note: Table provided by survey participant from the Kenyan National Biosafety Authority (NBA).

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway