GHENT UNIVERSITY

Faculty of Bioscience Engineering

Academic year 2018-2019

Farmers' Perspectives on Agricultural Biotechnology: Case Studies of Burkina Faso and Kenya

Edouard Idrissa Rachid Sanou

Thesis submitted in fulfillment of the requirements for the degree of Doctor (PhD) in Applied Biological Sciences: Agricultural Sciences

FACULTY OF BIOSCIENCE ENGINEERING

Promoters:

Pr. Dr. ir. Stijn Speelman
Department of Agricultural Economics
Ghent University

Pr. Dr. Godelieve Gheysen
Department of Biotechnology
Ghent University

Dean: Prof. dr. ir. Marc Van Meirvenne

Rector: Prof. dr. ir. Rik Van de Walle

Members of the Examination Broad

Prof. dr. ir. Guy Smagghe (chairman)

Faculty of Bioscience Engineering, Department of Plants and Crops, Ghent University

Prof. dr. Carl Lachat (Secretary)

Faculty of Bioscience Engineering, Department of Food technology, Safety and Health, Ghent University

Dr. Hans De Steur

Faculty of Bioscience Engineering, Department of Agricultural Economics, Ghent University

Dr. Hossein Azadi

Faculty of Sciences, Department of Geography, Ghent University

Prof. dr. Dorington O. Ogoyi

Chief Executive Officer (CEO) of National Biosafety Authority, Kenya.

Dutch Translation of the Title

Het Perspectief van Landbouwers op Agro-biotechnologie: onderzoek in Burkina Faso en Kenia

Suggested way of citation:

Sanou, E.R.I. (2019). Farmers' perspectives on agricultural biotechnology: Case studies of Burkina Faso and Kenya. Doctoral dissertation, Ghent University, Belgium

ISBN: 978-94-6357-183-8

Acknowledgements

This PhD journey has been quite an experience for me personally. As they say “a journey is more about whom you travel with, other where you go”. During my PhD study, I have received great help and support from my promoters, my jury members, my research group, my family, friends and from various institutions.

I would like to start by acknowledging the contributions of my promoters: Prof. dr. ir. Stijn Speelman and Prof. dr. Godelieve Gheysen. I would like to say thank you very much for all your great help, support, understanding and encouragement during my PhD. I would like to say thank you very much for all the valuable lessons that I will take with me not only in this PhD but also in my life after the PhD.

I would like to thank the jury members a lot for their valuable and constructive comments that help me a lot to improve my thesis. Prof. Smagghe, I would like to say thank you very much for being the Chairman of my PhD committee. Prof. Lachat, I would like to say thank you very much for the valuable comments and very helpful supporting materials for my thesis. Dr. De Steur, I would like to say thank you very much for your valuable advices and great support to improve my thesis. Dr. Azadi, I would like to say thank you very much for your valuable comments that help me a lot to improve my thesis. Prof. Dorington, I would like to say thank you very much for your valuable comments for my thesis and for all your great help and support during my PhD study.

Doing a PhD study in a new environment, new country, new weather can be very challenging, and I was no exception here. To sail through, I needed a shoulder(s) to lean on a number of accessions. These shoulders were offered by my research group over the past four years; Juan, Gonzalo, Janet, Aung, Wolde, Tian, Au, Miguel, Cecilia, Fekadu and Christian. I am grateful to the others colleagues of de department and the secretary team. Your diverse personalities, experience and approach to things impacted on my life in ways I couldn’t imagine, and I am forever grateful for having met and worked with each of you.

I would like to say thank you very much to my co-authors, Obi, Juan, Hans, Fabio, Bazoumana, Caspard and Vitale for your great contributions during this PhD’s articles.

What would I be without my family? I have made it this far because you never cursed me, even when you had the chance to do so. Instead, you encouraged me, loved me, and taught me ways of life which made me believed I can always make it in life irrespective of my circumstances. To my dad, Seydou SANOU, mum Suzanne M. L. PALE, you are God sent parents to me. To my siblings; Victoire, Sonia, Armel and Mamadou (RIP), I am so grateful for your endless support and love.

To the institutions such INERA (Burkina Faso), SOFITEX (BurKina Faso), IPBO (Belgium) and National Biosafety Authority (Kenya), I would like to express my gratitude for all your supports you provided during this PhD journey.

Par ce présent document de dure labeur, je voudrais m'incliner devant l'amitié et le soutien indéfectible témoigné par [Mr./Mme Sawadogo (Salifou), Mr./Mme SIA (Jacob), Mr./Mme Ouedraogo (Parfait), Mr./Mme Sanou (Boureima), Mr./Mme Bayoulou (Jonas), Mr./Mme Traore (Doulaye), Mr./Mme Bayala (romaric), Mr./Mme Ouedraogo (Bachir), Mr./Mme Sanogo (Ladji), Mr./Mmes Ousse (Albert, Oncle), Mr./Mme Mogendi (Kenya), Pr. Dicko, Dr. Dakuo, Hugo (France), Martin (Allemagne), Liliane (belle-sœur), Yacouba (beau-frère) Appoline (cousine), Karim, Diakite, Lassina, Alexis, Yvonique, Ali et Mlle Dio Stéphanie] tout au long de cette thèse. Puisse Dieu nous garder longtemps ensemble.

And last but not least, I would like to thank God for this astonishing life.

Financial support: This study has been financed with grants received from the Research Foundation - Flanders (FWO) –ERAfrica (project GA.013.14N). I am highly grateful to all the partners (Belgium, Netherlands, Kenya, South Africa and Burkina Faso) involved in the "SOCBIOAFRI" project.

Dedication

Dad, ***Seydou SANOU***

Mum, ***Marie Laure Suzanne PALE***

Sisters, ***Victoire and Sonia***

Brothers, ***Armel and Mamadou (RIP)***

Niece and Nephews: ***Cannel, Imran, Brad, Idem, Amir and Lawal***

Your love, encouragement, mentorship and sacrifices made me who I am today!

I hope I have made you proud!

Table of Contents

Promoters: i
Members of the Examination Broad..... ii
Dutch Translation of the Title iii
Acknowledgements iv
Dedication vi
Table of Contents vii
List of Tables..... xi
List of Figures xii
List of Abbreviations..... xiii
Summary xv
PART ONE: GENERAL INTRODUCTION 1
Chapter 1: Introduction..... 2
1.1. Defining Biotechnology, agricultural biotechnology and GM technology 2
1.2. Opportunities of Genetically Modified (GM) technology in Africa 2
1.2.1. Productivity increases and food security 3
1.2.2. Health and environmental benefits 4
1.2.3. GM technology and future prospects..... 5
1.3. Current status of GM technology in Africa 5
1.4. Problem statement 7
1.5. Conceptual framework 8
1.6. Description of study areas and study focus 12
1.6.1. Cotton and Sorghum in Burkina Faso 12
1.6.2. Maize in Kenya..... 13
1.7. Research objectives and research questions 14
1.8. Research design and data source 15
1.9. Thesis outline 16
PART TWO: Bt Cotton Event..... 18
Chapter 2: Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso 19
Abstract 19
2.1. Introduction 20
2.2. Background 21
2.3. Materials and Methodology..... 23

2.3.1. Study sites and sampling design 23
2.3.2. Structure of the questionnaire 24
2.3.3. Data collection 24
2.3.4. Statistical analysis 24
2.4. Results 26
2.4.1. Basic demographic profile of farmers 26
2.4.2. Farmers' knowledge and understanding of biotechnology and Bt-technology and its use 27
2.4.3. Farmers' perceptions about Bt-technology effectiveness in cotton production 28
2.4.4. Farmers' opinions concerning Bt-technology 28
2.4.5. Farmers' opinions regarding the health and environmental effects of growing Bollgard II® cotton 29
2.4.6. Farmers' behavioral practice in pest control management 33
2.4.7. Farmers' opinions about Bt seed cost and the decision to forsake Bollgard II® cotton 33
2.5. Discussion 34
2.6. Conclusion and recommendations 38
Chapter 3: What kind of biotechnology do farmers prefer? A Discrete Choice Experiment Approach considering Cotton Cultivation in Burkina Faso 40
Abstract 40
3.1. Background and Introduction 41
3.2. Cotton Cultivation in Burkina Faso 42
3.3. Discrete choice in cotton cultivation 43
3.3.1. Sampling Method 43
3.3.2. Discrete Choice Approach 43
3.4. Results and Discussion 47
3.4.1. Farmer characteristics 47
3.4.2. Conditional Logit 48
3.5. Conclusion 51
PART THREE: Biofortified Sorghum Event 53
Chapter 4: Farmers' Valuation of Transgenic Biofortified Sorghum for Nutritional Improvement in Burkina Faso: A Latent Class Approach 54
Abstract 54
4.1 Introduction 55
4.2 Choice Experiment Method 58
4.2.1. Theoretical Framework 58
4.2.2. The Choice Experiment Design 60
4.2.3. Sampling and Data Collection 63
4.2.4. Data Analysis 65

4.3 Results and Discussions 65
4.3.1. Socioeconomic and Farm Characteristics.. 65
4.3.2. Motivational Factors.. 67
4.3.3. Result of the Latent Class Model 68
4.3.4. Socio-economic and Motivational Factors Influencing Farmers Valuation................. 70
4.3.5. Farmers Willingness to Pay for Attribute Changes 73
4.4 Conclusion and Recommendations 74
PART FOUR: Bt maize Event 76
Chapter 5: Ex-ante Assessment of the Determinants of Farmers' Intention to Adopt Bt Maize in Kenya.. 77
Abstract 77
5.1. Introduction 78
5.2. Methodology 79
5.2.1. Background of the study.. 79
5.2.2. Survey sites... 80
5.2.3. Design of the questionnaire 80
5.2.4. Data collection and Analysis 81
5.3. Results 83
5.3.1. Socio-economic and farm characteristics of household 83
5.3.2. Farmers' perceptions of stem borer issues in maize production in Kenya 84
5.3.3. Farmers' knowledge of agricultural biotechnology and awareness of the GM maize event in Kenya... 85
5.3.4. Farmers awareness of the perceived effectiveness of GM technology....................... 86
5.3.5. Factors influencing farmers' intention to adopt GM maize seeds.............................. 89
5.3.6. Farmers' awareness of the GM maize drivers and preferred GM variety 90
5.4. Discussion and conclusion 93
5.4.1. Farmers' knowledge of agricultural biotechnology and GM technology in Kenya 93
5.4.2. Misunderstanding of the GM maize variety objective in Kenya................................ 93
5.4.3. Demand for insect-resistant variety in Kenya 93
5.4.4. Factors influencing farmers' intention to adopt GM maize.. 94
5.5. Recommendations 95
PART FIVE: GENERAL CONCLUSION.. 97
Chapter 6: Conclusion 98
6.1. Recapitulation of research questions.. 98
6.1.1. Bt cotton event: research questions RQ1, RQ2, RQ3, RQ4 and RQ5 98
6.1.2. Biofortified Sorghum event: research questions RQ6, RQ7 and RQ8 100
6.1.3. Bt maize event: research questions RQ9, RQ10, RQ11 and RQ12 100

6.2. Comparative discussion on farmers' perspectives on different GM crop events 101
6.2.1. Comparing the perspectives on GM cotton and biofortified sorghum attributes 101
6.2.2. Comparing perspectives between countries with different levels of experience on GM crops 103
6.2.3. Comparing the impact of the socio-demographic and farm characteristics on GM events 104
6.3. Implications and recommendations 104
6.4.1 Empirical contributions 104
6.4.2 Recommendations........ 105
6.4. Limitation of the study and future research........ 106
Appendices 108
Appendix A1. Original survey questionnaire for cotton producers 108
Appendix A2. Sample of Discrete Choice Experiment surveys with........ 112
Appendix A3. Questionnaire of Biofortified sorghum surveys in Burkina Faso 115
Appendix A5. Questionnaire toward surveys in Kenya 119
References 127
Samenvatting 149
Curriculum Vitae 151

List of Tables

Table 1.1: GM crop traits being developed or in commercial production (*) in Africa…………………..7
Table 1.2: Research design and data source…………………………………………………………...16
Table 1.3: Thesis outline………………………………………………………………………………17
Table 2.1: Structure of the questionnaire……………………………………………………………….25
Table 2.2: Basic demographic background of the farmers surveyed………………………………..26
Table 2.3: Farmers' knowledge towards Biotechnology and Bt technology core concept……………30
Table 2.4: Farmers' understanding of Bt technology use……………………………………………...30
Table 2.5: Farmers' perception about Bt technology effectiveness……………………………………31
Table 2.6: Farmers' opinions about Bt technology advantages………………………………………..32
Table 2.7: Farmers' opinions regarding health and environmental saving by growing Bt cotton…….32
Table 2.8: Farmers' behavioral practice in pest control management…………………………………33
Table 2.9: Farmers' opinions about the decision to forsake Bt cotton………………………………...34
Table 3.1: Attribute and levels of Attributes for the Choice Experiment………………………………46
Table 3.2: Example of choice set addressed to Small farmers group…………………………………...47
Table 3.3: Basic demographic background and yield component from the farmers surveyed…………48
Table 3.4: Utility Derived from all sample……………………………………………………………..49
Table 3.5: CLM estimation based on the type of farmers………………………………………………50
Table 3.6: WTP for Attribute level changes……………………………………………………………51
Table 4.1: Attributes and levels of attribute for Choice experiment…………………………………..61
Table 4.2: Socio-economic and Farm Characteristics of farmers………………………………………66
Table 4.3: Principal Component Analysis Result (N = 150)…………………………………………..68
Table 4.4: Conditional Logit Representing Utility Derived from Sorghum Attribute…………………..70
Table 4.5: Information Criteria for Determining the Optimal Number of Class………………………..71
Table 4.6: The LCM estimate for transgenic sorghum seed attribute…………………………………...73
Table 4.7: Farmers Willingness to Pay for a Change in Attribute……………………………………..74
Table 5.1: Design of the questionnaire………………………………………………………………...82
Table 5.2: Socio-economic and farm characteristics of household……………………………………84
Table 5.3: Presence of insect groups and perceived impact of stem borer species in maize production in Kenya……………………………………………………………………………………………..85
Table 5.4: Awareness of the GM maize event and Knowledge of agricultural biotechnology……….86
Table 5.5: Farmers' perceptions of the advantages of GM maize……………………………………...88
Table 5.6: Determinant factor influencing farmer intention to adopt by binary logistic regression ….90
Table 5.7: Farmers' awareness of the GM maize drivers, field trial outcomes and the preferred GM variety…………………………………………………………………………………………………92

List of Figures

Figure 1.1: Conceptual framework…………………………………………………………………..11

Figure 2.1: Cotton growing zones in Burkina Faso (Sofitex, Socoma et Faso Coton)…………………..23

Figure 4.1: Example of choice Set…………………………………………………………………..63

Figure 5.1: Sites of the study………………………………………………………………………..83

List of Abbreviations

ABS: African Biofortified Sorghum

AHI: African Harvest International

AIC: Akaike Information Criteria

AICB: Association Interprofessionnelle des Cotonculteurs du Burkina Faso

ANOVA: Analysis of Variance

ASC: Alternative Specific Constant

ATC: Agent Technique Coton, Burkina Faso

BIC: Bayesian Information Criteria

Bt: Bacillus thurengiencis

CE: Choice Experiment

CIMMYT: International Maize and Wheat Improvement Centre

CL: Conditional Logit

DCE: Discrete Choice Experiment

EIQ: Environmental Impact Quotient

EP: European Parliament

FAO: Food and Agriculture Organization of the United Nation

GE: Genetically Engineering

GM: Genetically Modified

GMO: Genetically Modified Organism

GPC: Groupement des Producteurs de Coton, Burkina Faso

IFPRI: International Food Policy Research Institute

INERA: Institut National de l'Environnement et de la Recherche Agricole, Burkina Faso

KARI: Kenya Agricultural Research Institute

LCM: Latent Class Model

MNM: Micronutrient Malnutrition

NGO: Non-Governmental Organization

OPV: Open Pollinated Variety

RQ: Research Question

SOFITEX: Société des Fibres et Textiles du Burkina Faso

SQ: Status Quo

SSA: Sub-Saharan Africa

UNPCB: Union Nationale des Producteurs de Coton du Burkina Faso

WTP: Willingness To Pay

Summary

Since the first commercial release of GM crop in mid-1990s, over the last two decades the implementation of GM technology in agriculture has been fueling a scientific and increasingly societal debate. Linking the rapid adoption of GM crops to the substantial multiple benefits realized by both large and small farmers in industrial and developing countries which have commercially grown GM crops, the majority of scientific studies have positioned agricultural biotechnology as a feasible solution to alleviate the issue of malnutrition and food insecurity in developing countries. This view is also shared by International Organizations (e.g. FAO and World Bank).

Even though, substantial agronomic, environmental, economic, health, and social benefits linked to the adoption of GM crops were attributed to farmers, and increasingly to the consumers in various studies, agricultural biotechnology remains a controversial subject, mostly in Europe and Africa. However, despite the intense ongoing political debate about the adoption of GM crops in both continents, the majority of soybeans used in European food and feed is imported and more than 75% of the global soybean production is GM. Regarding Sub-Saharan Africa, although for the few African countries that currently grow GM crops (South Africa and Sudan), or that have done it in the past (Burkina Faso) agronomic, environmental and health benefits for farmers were reported, GM technology uptake is still subject to a fierce debate between proponents and opponents.

In contrast to Europe, farmers' voice on GM technology application in Africa seems to be lagging behind or to be under-considered in the debate about the development, implementation or regulation of agricultural biotechnology. Moreover, African farmers' opinions on this controversial issue appeared to be seldomly accounted for in scientific research. For this purpose, this PhD dissertation investigates farmers perspectives on agricultural biotechnology in Sub-Saharan Africa. This study was conducted in West (Burkina Faso) and East (Kenya) Africa.

This Ph.D. research was also inspired by a need to examine farmers' perspectives towards the implementation of GM technology in food (maize and sorghum) and non-food (cotton) crops, while considering first (Bt maize and Bt cotton) and second (biofortified sorghum) generation of GM crops. Thus, the research objectives of this doctoral dissertation can be formulated along the three GM crop events investigated (Bt maize, Bt cotton and biofortified sorghum). Firstly,

the objective is to explore farmers' knowledge, understanding and opinion on the implementation of Bt cotton in the farming system of Burkina Faso. It also seeks to understand farmers' preferences for GM cotton varieties. The second objective was to determine farmers' willingness to cultivate nutrient bio-fortified sorghum variety. Finally, for the Bt maize event in Kenya, the objective is to examine the factors influencing farmers' intention to adopt Bt maize. To explore the research objectives, data were collected using face-to-face surveys. A total of 324 and 150 household heads were respectively interviewed in Burkina Faso and in Kenya.

When analyzing the first research objective, results show that knowledge of farmers concerning biotechnology and Bt-technology is limited and depends on their education level and their role within producer's group (GPC). Even though the majority of the farmers were satisfied with the adoption of Bollgard II® cotton, data from the Choice Experiment (CE) surveys of this study underline that farmers preferences in Burkina Faso are mainly influenced by the economic benefits (higher yields, lower seed costs) and reduced pesticide use. Moreover, the study found that the regulatory oversight in the implementation of the Bt-technology is insufficient. Farmers knowledge of suitable pest management strategies is low. Finally, the decision to forsake Bollgard II® cotton in Burkina Faso was badly perceived by the majority of the farmers.

Results regarding the second research objective reveal that although there is awareness of farmers on micronutrient deficiency, they have limited knowledge on transgenic biofortification. However, the latent class model looking at biofortified sorghum shows that more than 60% of the farmers would be prepared to cultivate a transgenic sorghum variety. Regarding the outcomes of the last GM event investigated, the study found that only few Kenyan farmers (14%) correctly associate Bt maize with resistance against stem borers. Although our binary logistic regression model showed that the number of stem borer species faced by farmers is the key factor for the future adoption, regional differences in perceived damage caused by stem borers impact the intention-to-adopt. Furthermore, in the Western region of Kenya, older farmers are more likely to adopt a GM variety compared to younger farmers. For farmers in the Eastern region, the perception about the environmental benefits, due to the lower use of pesticides, was identified as a key determinant shaping behavioral intention towards GM seed adoption.

From the study findings, this PhD dissertation has three important contributions. Firstly, the study fills a gap in literature by studying Sub-Saharan African farmers' perspectives on GM technology application in agriculture. Secondly, it provides insight into African farmers' preferences for GM varieties characteristics, whether food or non-food crops. From a policy perspective, the last contribution of this study can be related to the attention that was given to the institutional framework for development and implementation of GM crops.

PART ONE: GENERAL INTRODUCTION

Chapter 1: Introduction

1.1.Defining Biotechnology, agricultural biotechnology and GM technology

Biotechnology has broadly been defined as any technique that uses living organisms or substances from those organisms, to make or modify a product, to improve plants, animals or microorganisms for specific uses (Bailey et al., 2014). Generally defined, agricultural biotechnology comprises tissue culture techniques, mutation breeding, recombinant DNA technology, the use of molecular markers for breeding, and genetic modification using transgenes to develop GM crops (Khan and Joyia, 2018). Biotechnology as applied in agriculture, offers a wide variety of scientific approaches to improve plants, aiming at developing solutions to improve agricultural productivity and sustainability (Lokko et al., 2018).

Advances in plant biotechnology have greatly enlarged the gene pool, making it possible to transfer defined genes into all major food and non-food crops (Vasil, 1998). Following the type and strategy used GM crops can be classified into four generations (Lin and Pan, 2016). The first generation comprising a single trait, the second characterized by stacked traits, the third and the fourth generations grouping near-intragenic, intragenic and cisgenic methods (Holst-Jensen et al., 2012).

Another way of classifying which is used in this doctoral thesis considers the objective of the genetic modification. GM plants of first generation are those with input traits basically related to increase insect and herbicide resistance. The second generation presents output traits to benefit the consumer, aiming mainly to add value to the final product through nutritional improvement or better storage conservation (Caserta and de Souza, 2017; Stewart and McLean, 2005; Halpin, 2005).

1.2. Opportunities of Genetically Modified (GM) technology in Africa

GM crops could be beneficial for the African continent because of their potential to promote food security and sustainable agriculture. These crops open the possibility of addressing biotic and abiotic constraints to food, feed, and fiber production (IFPRI, 2013). At one hand GM crops may enhance productivity, improve pest and weed control, and increase tolerance to drought and salinity. At the other hand these crops might also be beneficial by improving public health through reductions in pesticide applications or through enhanced nutrition, by adding micronutrients to staple crops (Qaim, 2010, IFPRI, 2013, Bazuin et al., 2011:; Taheri et al., 2017; Zilberman et al., 2018). In this way they potentially target many key challenges.

1.2.1. Productivity increases and food security

Africa faces the challenge of meeting food security as its growing population approaches one billion. Sub-Saharan Africa (SSA) is the region at greatest food security risk because by 2050 its population will increase 2.5-fold and demand for cereals will approximatively triple, whereas current levels of cereal consumption already depend on substantial imports (Van Ittersum et al., 2016). In SSA, the prevalence of undernourishment appears to have risen from 20.8 to 22.7 percent between 2015 and 2016, and the number of people undernourished rose from 200 to 224 million, accounting for 25 percent of 815 million people undernourished in the world in 2016 (FAO, 2017).

Agriculture is crucial for attaining food, feed and fiber security (Borlaug, 2007). However, African agricultural systems are clearly operating under considerable stress, and the situation will only worsen with food needs of the increasing population (FAO, 2015). Cereal crop yields in SSA have stagnated over the last 40 years, averaging only 1 ton per hectare, while the meager harvests are further reduced by pests and diseases (Nang'ayo et al., 2014). Bazuin et al. (2011) link this lack of intensification of cereal production in Africa to the failure of the "green revolution[1]" and identified some features of African agriculture which explain this failure, such as: i) lack of dominant farming systems, ii) predominance of rainfed agriculture as opposed to irrigation, and iii) prevalence of soils of poor fertility (Thomson, 2007). However, in the coming decades failure to lift up productivity will result in increasing dependence on cereal imports or will need a vast expansion of rainfed cropland area, especially because the population in SSA is projected to further increase between 2050 and 2100 by a factor 1.9. Furthermore, anticipated climate change will make the situation even more challenging (Van Ittersum et al., 2016).

The necessary increase in cereal productivity cannot be brought in such a short period of time by conventional breeding (Vasil, 1998). The low agricultural productivity in Africa should be addressed by innovative science (Juma, 2011). The application of GM technology has been proposed within the technology mix to improve Africa's agricultural productivity (FARA,

[1] The green revolution refers to set of research and technology transfer initiatives occurring after WWII, that increased agricultural production worldwide, particularly in the developing world. It included high-yielding varieties (HYVs) of cereals in association with chemical fertilizers, agro-chemicals, irrigation and new methods of cultivation, including mechanization. All of these together were seen as a 'package of practices' to supersede 'traditional' technology and to be adopted as a whole (*Farmer, B. H. (1986). "Perspectives on the 'Green Revolution'in South Asia". Modern Asian Studies.* ***20*** *(01): 175–199.)*

2011; Juma and Serageldin, 2007). Evidences from India (Qaim and Kouser, 2013) and South Africa (Morris and Thomson, 2014) have proven that GM crops can substantially contribute to meet the challenge of food security by increasing yields (Klumper and Qaim, 2014; Zilberman et al., 2018)

1.2.2. Health and environmental benefits

Beyond the need for increased production, there are challenges of environmental sustainability, public health and malnutrition. According to Reynolds et al. (2015) concerns have been growing that farming practices themselves, in Sub-Saharan Africa are exacerbating biotic and abiotic constraints on food production through negative impacts on the environment (Poppy et al., 2014; Dogliotti et al., 2014; Chartres and Noble, 2015). Examples of environmental degradation include agriculture-related deforestation, soil erosion, nutrient mining, water depletion, soil/water/air pollution, biodiversity loss, and climate change (Cassman et al., 2003; Keating et al., 2010; Phalan et al., 2011; Pretty et al., 2011; Tilman et al., 2011; Chartres and Noble, 2015). Deterioration of land and water sources is aggravated by the lack of strong regulatory policies in the import and use of pesticides (Traore et al., 2014). For example, the abusive use of insecticides in cotton cultivation in Burkina Faso was reported as a crucial hazard for farmers' health and environment (Hema et al., 2009; Vognan et al., 2002). GM technology is advocated as a solution to environmental degradation (Reddy et al., 2013). A recent assessment of environmental impacts of GM crops used from 1996 to 2015 showed that the adoption of GM insect resistance and herbicide tolerance technology has reduced pesticide spraying by 618.7 million kg (-8.1%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use (as measured by the indicator, the Environmental Impact Quotient (EIQ)) by18.6% (Brookes and Barfoot, 2017). Similarly, environmental and health benefits were noticed from Bt cotton production in Burkina Faso, Soudan and South Africa (ISAAA, 2016).

Regarding the issue of malnutrition, micronutrient deficiency is pointed out as an important contributor to the global burden of diseases (IFPRI, 2016). Globally, micronutrient deficiencies afflict more than two billion individuals (FAO, 2015). Over the last 50 years, production and availability of calorically dense staple crops has increased in developing countries, but this has not happened in equal measure for micronutrient-rich non-staples, such as vegetables, pulses and animal products (Bouis and Saltzman, 2017). In addition, prices for non-staple food have gone up substantially, making it increasingly difficult for the poor to afford dietary quality (Bouis et al., 2011). Biofortification of staple crops which is the process of increasing the density of vitamins and minerals in food, can be a solution. In this way crops can be engineered to fight malnutrition (Khan et al., 2016; AHBFI, 2007). Biofortification can be done by breeding with plants rich in essential micronutrients (Bouis et al., 2011). If such plants are not available in the breeding pool, genetic engineering is another way in which micronutrient content in plants can be enhanced (De Steur et al., 2017). While the development of golden rice was announced in 2000 as a milestone to fight against the deficiency of vitamin A in humans (Ye et al., 2000), to date, none of the developed GM biofortified crops are currently approved for cultivation. Since 2003, HarvestPlus, a programme that has led a global effort to breed and disseminate biofortified staple crops has made substantial progress in research to enhance content of vitamin A, Zinc and Iron in seven crops: cassava, maize, sweet potato, bean, pearl millet, rice, and wheat (Ruel et al., 2013). Uptake of biofortified crops will also have positive longterm effects on society, because it can solve the issue of children being stunted, increasing labour productivity and income earning potential (FAO, 2017).

1.2.3. GM technology and future prospects

Due to the rise of the global bioeconomy and the need for sustainable development, agricultural biotechnology is becoming increasingly important for Africa. The modern bioeconomy typically can provide not only food but also non-food products from managed agricultural, aquaculture and forestry ecosystems (Lokko et al., 2018). Moreover, engineered plants have been shown to be useful in phytoremediation to decontaminate soils containing heavy metals and other toxic substances (Vasil, 1998).

1.3. Current status of GM technology in Africa

Although the African continent remains the region with the biggest potential to reap from the benefits associated with modern agricultural biotechnology (ISAAA, 2017), the technology uptake is lagging behind (Okeno et al., 2013). This in spite of the fact that the African continent is the most exposed to food and nutrition insecurity (Mugiira et al., 2015). The introduction of genetically engineered crops, which is one specific version of biotechnology, has met social resistance because of presumed potential negative effects on public health, the environment, socioeconomic conditions and trade (Ficher et al., 2015). In Sub-Saharan Africa, biotechnological applications driven by international private companies have particularly met resistance because of issues concerning intellectual property rights and their possible negative effects on local agricultural practices (Bowman, 2015; Wield et al., 2010; Lewin, 2007; Chataway, 2005). Moreover, one of the crucial reasons explaining the slow uptake of the GM technology in Africa could be related to the strong multidimensional relationship between

Africa and the European Union countries. European politicians and NGOs that oppose GMOs are similarly very active at disseminating their ideas to stop the use of this technology in Africa as well, where agricultural innovation is a necessity for food security. Exemplary for the European pressure was the report made by the Members of the European Parliament and adopted by that Parliament in 2016 (EP resolution, June 7, 2016) that calls for not supporting the use of GM crops in Africa.

Furthermore, public perceptions, which are often rooted in local culture and ethics, appear to have a critical role in the societal acceptance of biotechnology (Azadi et al., 2017; Fischer and Eriksson, 2016). At the other hand, many farmers are currently unable to access GM technologies due to weak regulatory systems, hesitant politics and the absence of regional biosafety harmonization strategies (Schurman, 2017; Azadi et al., 2015; Mabaya et al., 2015; Adenle, 2014).

However, experience over the past two decades of GM crops has proven that the technology presents real health and environmental benefits to farmers taking cue of the showcases of South Africa in 1998, Egypt and Burkina Faso in 2008 (James, 2009), and more recently in Soudan (James, 2016). According to the latest brief regarding the global status of commercialized biotech/GM crops (ISAAA, 2017), GM crop field testing is ongoing in thirteen countries, targeting twelve crops and using 14 traits offered by GM technology (Table 1.2). But only South Africa (Bt cotton and Bt maize) and Sudan (Bt cotton) are currently commercializing GM seeds. Burkina Faso, which is the focus of two of our study cases, was cultivating Bt cotton from 2008-2016.

Table 1.1: GM crop traits being developed or in commercial production (*) in Africa (source: ISAAA 2017)

Crop	Country	Traits
Banana	Uganda, Malawi, Kenya	Biofortified, Black sigatoka, Banana bacterial-Xanthomonas wilt (BXW) resistance
Banana Plantain	Malawi	Bunchy top virus resistance
Cassava	Kenya, Nigeria, Uganda	Cassava mosaic Disease, Cassava brown streak Disease, Delayed postharvest starch deterioration
Cowpea	Burkina Faso, Ghana, Malawi, Nigeria	Maruca resistance (insect resistance)
Cotton	Ethiopia, Kenya, Nigeria, Swaziland South Africa (*), Soudan (*)	Insect (bollworm) resistance
Gypsophila Flower	Kenya	Pink coloration of petals
Maize	Kenya, Mozambique, Nigeria, Tanzania, South Africa (*), Uganda	Insect resistance (IR), Drought tolerance (DT), Stacked IR/DT
Potato	Uganda	Late blight
Rice	Burkina Faso, Ghana, Nigeria, Uganda	Nitrogen Use Efficiency, Water Use Efficiency
Sorghum	Kenya, Nigeria	Biofortified
Sweet potato	Kenya	Sweet potato virus disease resistance
Soybean	South Africa	Stacked trait with modified fatty acid composition

1.4. Problem statement

As described above, GM crops are the topic of a controversial debate ever since their introduction in 1996 (Areal et al., 2011). Also in the scientific community there has been a lot of attention for GM crops. While in the first place a lot of research has been done on the agronomic and economic performance and on the human health and environmental risks associated to GM crops (Areal et al., 2011), also stakeholders' attitudes on GM crops have received quite some attention (eg. Kikulwe et al., 2011; Frewer et al., 2013). The second type of research however has mainly focused on consumers' attitudes and preferences, overlooking other stakeholders, particularly farmers (Bett et al., 2010). Farmers and in Africa particularly smallholder farmers are however the ones most likely to be affected by the introduction of GM crops. In this light, it is strange that they are least included in public debates and consultation about the development, implementation or regulation of this agricultural biotechnology and that their perspective is also only to a limited extend taken into account in literature. Nevertheless, information on the opinion of farmers is instrumental for shaping a more evidence-based frontier in the debate on the importance of GM crops for Africa. Farmers are the potential producers of GM crops and adoption among smallholders will determine the success of agricultural biotechnology in potentially improving food security (Oparinda et al., 2017) or tackling other challenges. In addition, the regulatory frameworks for the introduction and use of genetically modified (GM) crops more and more require that socio-economic impacts (SEI) are taken into account. This should go beyond simple monetary indicators (Catacora Vargas et al., 2017).

1.5. Conceptual framework

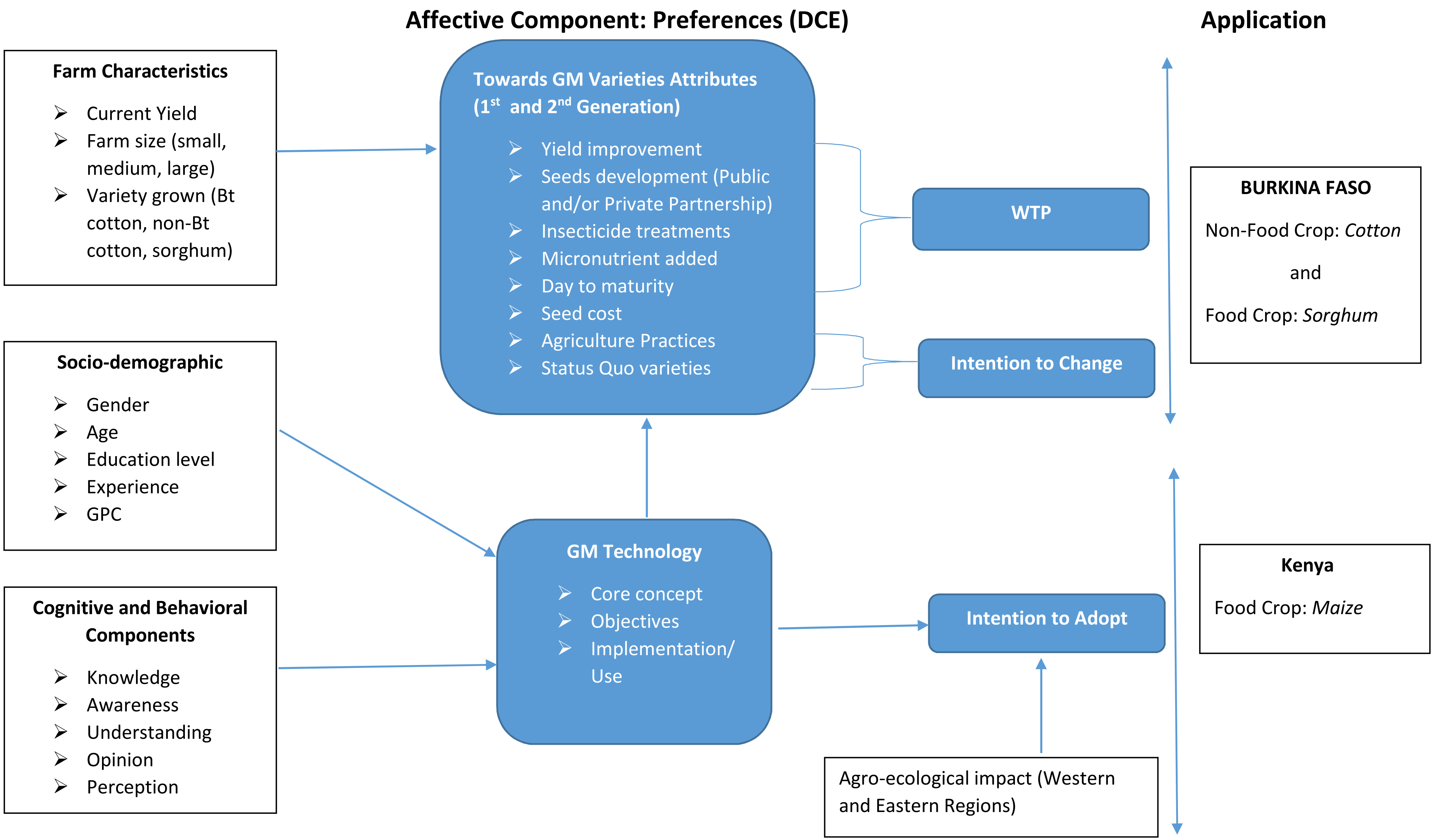
The aim of this doctoral dissertation is to investigate farmers' perspectives on agricultural biotechnology. The conceptual framework is presented in figure 1.1. Given that this thesis research was conducted as part of the project "*Addressing Social Challenges of Biotechnology in Africa. Towards balanced Innovation* (SocbioAfri)," this conceptual framework captures the GM technology implementation in Burkina Faso (West Africa) and Kenya (East Africa) as initially expected. Moreover, this study considers on the one hand the application of GM technology in food crops (maize and sorghum) and non-food (cotton) crops, and on the other hand, the first (Bt maize and Bt cotton) and the second generation (biofortified sorghum) of GM crops.

In order to contextualize farmers' perspectives on GM technology, cognitive (knowledge, awareness, understanding), behavioral (perception, opinions) and affective (preferences) components were employed. This approach is following the model of attitude by Lavidge and Steiner (1961) containing three components (cognitive, affective and behavioral). Attitudes are generally considered to be made up of these three elements (Fiore and Kim, 2007). In this study, the cognitive components refer to farmers' knowledge (both objective and subjective knowledge), awareness and understanding about the GM technology application in agriculture. The lack of knowledge by farmers on agricultural biotechnology and the misunderstanding of the objective of GM technology is used by anti-GMO activists as a main concern in Sub-Saharan Africa (Bowman, 2015). Moreover, a recent *ex-post* study of Todua (2017) positioned the awareness about the GM technology as a key factor driving farmers' intention to adopt GM crops. Similarly, in South Africa, Kotey et al. (2017) argued that awareness of GM crop stewardship requirements is urgently needed to improve its management and exploit the benefits provided by the GM technology.

Behavioral components in this study are related to the perceived-effectiveness of the use of the GM technology as well as opinions on that. For instance, the insect-resistant GM crops are currently positively valued owing to the reduced use of pesticides (Vitale et al., 2011). Most studies have linked the fast adoption and spread of GM crops to the potential benefits in terms of farmers' health and the environment (Steawart and McLean, 2005). The perceived-effectiveness of GM technology implementation in cotton production in Burkina Faso had placed the country to be the first planter of GM crops in Africa in term of cultivated surface (Vitale and Greenplate, 2014). The last component (affective) used in this study is associated to farmers' preferences for GM crops. Literature has shown that there are more studies on the preferences of consumers (see for example the overview in the meta-analysis of Frewer et al., 2013) than of farmers (eg. Valdivia et al., 2014; Evans et al., 2017). Particularly for the African continent studies on farmers' preferences are scarce.

To understand farmers' preferences, a Discrete Choice Experiment (DCE) was developed in this thesis. The DCE was employed in Burkina Faso for two GM crop events (Bt cotton and biofortified sorghum). A DCE is commonly known as a robust method to analyze preferences for key attributes describing a product (Carson et al., 1994). In this context, typical product and production related factors (eg yield, insecticide treatment requirements, day to maturity seed price) were combined with an institutional aspect (seed development and distribution). The inclusion of this last attribute is of interest given the public concern regarding the prominence of multinationals in the development of these crops and this study is the first one to incorporate it in a DCE. Apart from preferences towards the attributes, by including the seed cost attribute also farmers willingness to pay (WTP) for all attributes can be established.

Farms (farm size, insect control) and socio-demographic (gender, age, education level, experiences, farmers organizations) characteristics might play a key role in the adoption of GM crops. Although there is limited documentation on farmers' attitudes towards GM technology, especially in SSA, some studies ((Keelan et al., 2009; Fernandez-Cornejo and McBride, 2002; Marra et al., 2001) suggested that large-scale farmers were more likely to adopt GM crops than small-scale farmers. Similarly, most studies suggest that older farmers are more reluctant than younger farmer to adopt GM varieties (Gyau et al., 2009; Boz and Akbay, 2005; Van Scharrel, 2003; Fernandez-Cornejo and McBride, 2002; Darr and Chern, 2002). In terms of gender, the investigation of Guehlstorf (2008) showed that females were more likely to adopt GM crops than males due to the reduction of labor requirements. More recently in Uganda, the *ex-ante* analysis by Schnurr and Addison (2017) revealed that attitudes and potential patterns of adoption of GM crops vary significantly according to regions and membership in farmer's association. In this study, effects of farm related factors and socio-demographic characteristics on farmers' intention to adopt a GM maize variety in Kenya were investigated with specific attention for the differences between farmers of the Western and Eastern region.


Affective Component: Preferences (DCE)
Application
Farm Characteristics
Current Yield
Farm size (small, medium, large)
Variety grown (Bt cotton, non-Bt cotton, sorghum)
Towards GM Varieties Attributes (1st and 2nd Generation)
Yield improvement
Seeds development (Public and/or Private Partnership)
Insecticide treatments
Micronutrient added
Day to maturity
Seed cost
Agriculture Practices
Status Quo varieties
WTP
Intention to Change
BURKINA FASO
Non-Food Crop: Cotton
and
Food Crop: Sorghum
Socio-demographic
Gender
Age
Education level
Experience
GPC
GM Technology
Core concept
Objectives
Implementation/ Use
Intention to Adopt
Kenya
Food Crop: Maize
Cognitive and Behavioral Components
Knowledge
Awareness
Understanding
Opinion
Perception
Agro-ecological impact (Western and Eastern Regions)

1.6. Description of study areas and study focus

Two countries (Burkina Faso and Kenya) were included in this study. The choice for Burkina Faso (West Africa) was made because of its experience with Bt cotton cultivation and the development stage of the biofortified sorghum program. Kenya (East Africa) was considered based on the ongoing Bt maize project which has just got approval for limited environmental release, the final stage before commercial release. Both countries (Burkina Faso and Kenya) share the same main African agriculture features such as predominance of rainfed agriculture, lack of dominant farming systems as well as lack of strategies to protect crops from insect, pest and disease attacks.

1.6.1. Cotton and Sorghum in Burkina Faso

Cotton is one of the most important cash crops in West Africa and is a vital catalyst to economic development in the region (Vitale et al., 2007). In Burkina Faso, the cotton sector not only provides labor for more than 350,000 farmers[2], but also indirectly provides income to more than 3 million people, taking into account the entire value chain and that of by-products, such as local oil factories and cattle food producers (FAO, 2014). Around the year 2000, the government of Burkina Faso became interested in Genetically Modified (GM) cotton. At that time, the cotton sector was facing considerable problems with pest damage (Fitt, 2000), leading to a deteriorating socio-economic situation in the cotton sector (Renaudin et al., 2012). In collaboration with Monsanto, the national agricultural research institute INERA began a 5-year program of field testing of Bollgard II®, a second generation of *Bacillus thuringiensis* (Bt) improved cotton with insect resistance (Vitale et al., 2007). The first commercial release occurred in the 2008-2009 agricultural campaign (James, 2009). In the following years the area under Bt cultivation was growing very fast. However, in 2016, because of an issue with the length of the cotton fibers the cotton companies convinced the government of Burkina Faso to suspend the cultivation of the GM cotton variety (ISAAA, 2016).

Sorghum is the most important staple crop in Burkina Faso, cultivated by most farmers. However, the local sorghum cultivar is deficient in essential nutrients (da Silva et al., 2011; Traore and Stroosnijder, 2005). Under the collaborative framework with African Harvest International (AHI), Burkina Faso has undertaken the development of biofortified sorghum in

[2] In Burkina Faso, cotton producers are organized in small group at village level. This group is called GPC (groupement de producteurs de coton). Each GPC has a head (president), active member like secretariat or other position and simple member (a farmer who does not occupy a specific position within the group).

2010. The resulting African Biofortified Sorghum (ABS) would contain increased levels of vitamin A, Iron and Zinc.

1.6.2. Maize in Kenya

Maize (*Zea mays* L.) is the most important staple food in Kenya, accounting for 65% of total staple food caloric intake and 36% of total food caloric intake (Ariga et al., 2010). Following Shiferaw et al. (2011), East African (27 kg/capita/year) occupied the second rank after South Africa (85 kg/capita) in terms of highest amounts of maize consumed per year. Maize yields in Kenya are around 1.4 ton/ha, which is only 30% of the world average (FAO, 2000). Maize production in Kenya contributes to about 12% of the rural households' income (Mugo et al., 2005). However, its production is entirely dependent on rainfall, while only about 17% of the country is suitable for rainfed crop production. Despite the great efforts made to increase maize production, the demand has occasionally outstripped the supply, requiring import of large quantities of maize (Muhunyu, 2008).

There are numerous factors such as limited access to improved inputs (including improved maize varieties and fertilizers), recurrent drought, poor soil fertility, diseases, weeds and insect pests contributing to low maize yields in SSA (Smale et al., 2011; Shiferaw et al., 2011). Nevertheless, Odendo et al. (2003) placed Lepidopteran stem borers at the top of the most important factors, causing significant negative impact on maize yields in Africa due to their damage to the leaves, stem and ears. Along the same line, one of their studies conducted in Kenya in 2000-2001 revealed that stem borer damage was responsible for annual maize yield losses of on average 14%, about 0.4 million tons valued US$ 25-60 million, which was enough to feed 3.5 million people at a per capita maize consumption of 125 kg per annum.

Despite the development of new improved hybrid varieties in these two decades in Kenya (Muhunyu, 2008), domestic maize production is not keeping pace with the growing demand for maize. Imports have increasingly been filling the gaps left by insufficient domestic production (Wang et al., 2017). A solution to boost local production could be to control stem borer species. Consequentially, in 1999, the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI) launched the development of an insect-resistant GM maize variety (De Groote et al., 2003, Mwangi and Ely, 2001). To date, the GM maize variety has obtained approval for limited environmental release for National Performance Trials, the final stage before commercial release.

1.7. Research objectives and research questions

The research objectives of this doctoral dissertation can be formulated along the three GM crop events investigated. First, for the study on Bt cotton, which is an *ex-post* study, the objective is to explore farmers' knowledge, understanding and opinion on the implementation of Bt cotton in the farming system of Burkina Faso. A second objective linked to this event is to see to which extent the current GM cotton event, meets the preferences of farmers in terms of characteristics like yield, insecticide requirements, farming practices and seed provenance and cost.

Secondly for the biofortified sorghum, which is an ex ante study concerning a second generation GM food crop, the objective was to determine farmers' willingness to cultivate biofortified sorghum. This involved looking at farmers' awareness on micronutrient deficiency. Moreover, given that part of the sample selected for this study has experience with the GM cotton variety, one of the objectives of this *ex-ante* study was also to analyze the effect of experience with Bt cotton on the intention to adopt a biofortified sorghum variety. Previous experience with GM crops was stated as a determinant factor in the adoption of GM technology (Schnurr and Addison, 2017).

Finally, for the Bt maize event in Kenya the objective is to examine the factors influencing farmers' intention to adopt Bt maize. Again, this is a food crop, but this time a first generation GM crop, so with input traits (insect resistance) instead of output traits (added micro-nutrient). Moreover, unlike in the Burkina Faso case, Kenyan farmers have no previous experience with GM crops. An additional focus also is the comparison between the Western and Eastern region of Kenya. This ex-ante study investigated farmers' knowledge on GM technology implementation in maize and their understandings of the objective of the GM maize under development for commercialization.

The research objectives related to the three GM crop events can be translated in the following research questions (RQ).

For the Bt cotton event:

RQ1 What is the level of understanding and knowledge among cotton farmers in Burkina Faso about the core concepts of biotechnology and more specifically, Bt-technology?

RQ 2 What are the perceptions of cotton farmers in Burkina Faso towards Bollgard II®?

RQ3 What is the impact of the implementation of Bollgard II® on the pest management practices applied by cotton farmers in Burkina Faso?

RQ 4 How do cotton farmers evaluate the recent decision by government in Burkina Faso to suspend decision to suspend cultivation of Bollgard II®?

RQ 5 To what extent are the current characteristics of Bt cotton in line with famers' preferences?

For the biofortified sorghum event in Burkina Faso:

RQ6 What is the level of knowledge among farmers in Burkina Faso about micronutrient deficiency and transgenic biofortification?

RQ7 How do farmers in Burkina Faso value various sorghum seed attributes?

RQ8 How do characteristics of farmers influence farmers' preferences for sorghum attributes?

For the Bt Maize event in Kenya:

RQ9: To what extent are farmers aware about the development and the implementation of GM technology in maize production in Kenya?

RQ 10 How is farmers' understanding about the objective of this technology?

RQ11: What determines farmers' intention to adopt a GM maize variety in Kenya?

RQ 12 What are the key differences between Western and Eastern regions farmers?

1.8. Research design and data source

To investigate the research questions of this dissertation, data were collected in Burkina Faso and Kenya. The focus crops were food (maize and sorghum) and non-food (cotton) crops. Three GM events (Bt cotton, biofortified sorghum and Bt maize) were examined. Table 1.2 summarizes the research design and the data source as well as the statistical analysis performed.

In Burkina Faso, data were collected twice (July-September 2015 and April-May 2016). The first data set derived from the surveys of 324 cotton farmers. A stratified sampling method was developed for the data collection based on the farm size (small, medium and large), the type of variety grown (Bt and non-Bt cotton producers) and the agro-ecological characteristics (Bobo, Dedougou and Diebougou). The second data set collected in Burkina Faso focused on the biofortified sorghum event. Purposely, 150 farmers were selected in the first cotton sample while considering framers with experience in Bt cotton cultivation and farmers without any experience with GM cotton variety.

In Kenya, date collection was geared towards maize farmers households. A total of 150 farmers were interviewed with 100 farmers randomly selected in Western Kenya (the main maize region of the country) versus 50 farmers in Eastern region. The East region presented the lowest maize yield in Kenya. This survey was conducted from April to May 2017.

Table 1.2: Research design and data source

Study site	Focus crop	Thesis chapter	Survey sampling	Sampling target	Statistical analyses
Burkina Faso	**Cotton**	Chapter 2	n = 324	Farm size, Bt and non-Bt Cotton variety, Position in GPC	Descriptive statistics (chi-square, ANOVA, Cross-tabulation)
		Chapter 3	Survey with Choice experiment (n = 324)	Farm size, Bt and non-Bt Cotton variety	Conditional logit model with Alternative Specific Constant (ASC)
	Sorghum	Chapter 4	Survey with Choice experiment (n = 150)	Among cotton growers (Bt and non-Bt)	Factors Analysis, conditional logit model, latent class
Kenya	**Maize**	chapter 5	n = 150	Agro-ecological characteristics (west and east regions), Farm size	Descriptive statistics (chi-square, cross-tabulation, t-test), factor analysis, binary logistic regression

1.9. Thesis outline

The empirical part of this dissertation consists of a compilation of papers, some of which have been published in or accepted by international peer-reviewed journals, or that were presented at international conferences covering the scientific discipline of agricultural and applied economics as well as biotechnology-based agriculture. Each chapter can be read as a stand-alone, and repetitions were kept at minimum. However, in some chapters repetition might exist, which was necessary to provide context to the analysis.

Table 1.3 provides information about the thesis outline. It shows that this thesis dissertation is divided in 5 parts. The first and last parts represent respectively the introduction and the conclusion sections. The three main parts (2, 3 and 4) refer to the three GM events investigated in this thesis. Regarding the first GM event (Bt cotton), two chapters were developed. Four research questions were dedicated to the chapter 2. The fifth research question was explored in the chapter 3. In the third part of the thesis, the second GM event (biofortified sorghum) were investigated around three research questions in chapter 4. The last GM event (Bt maize) represents the part 4. Chapter 5 developed in this part analyses four research questions.

Table 1.3: Thesis outline

Part	GM crop event focus	Thesis chapter	Title of the chapter	Research question (RQ)
1		Chapter 1	Introduction	
2	**Bt cotton**	Chapter 2	Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso	RQ 1-4
		Chapter 3	What kind of biotechnology do farmers prefer? A Discrete Choice Experiment Approach considering Cotton Cultivation in Burkina Faso	RQ 5
3	**Biofortified sorghum**	Chapter 4	Farmers' Valuation of Transgenic Biofortified Sorghum for Nutritional Improvement in Burkina Faso: A Latent Class Approach	RQ 6-8
4	**Bt maize**	Chapter 5	Ex-ante Assessment of the Determinants of Farmers' Intention to Adopt Bt Maize in Kenya	RQ 9-12
5		Chapter 6	Conclusion	

PART TWO: Bt Cotton Event

Chapter 2: Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso[3]

Abstract

In 2008, the commercial cultivation of Genetically Modified (GM) cotton started in Burkina Faso. This GM cotton is Bollgard II®, which is resistant to the cotton bollworm because of the expression of a *Bacillus thuringiensis* (Bt) protein. The adoption rate increased rapidly in subsequent years to reach around 70% in 2014. Although some criticisms were raised concerning the suitability of the technology for the farming system in Burkina Faso, the introduction of transgenic cotton in the country was generally regarded as a big success. Despite this, during the 2016-2017 agricultural campaign, the government of Burkina Faso decided to suspend the cultivation of Bollgard II®. In this context, this paper investigates farmers' knowledge, perceptions, opinions and attitudes towards Bt cotton as well as their views on the recent decision to suspend its cultivation. Data was collected from 324 cotton farmers, both growers of conventional and Bt cotton. The results showed that the farmers surveyed had a poor knowledge concerning the core concepts of biotechnology and Bollgard II® in particular. Moreover, the regulatory oversight of the implementation of the technology was found insufficient, as illustrated by the lack of compliance with prescriptions concerning refuge areas and pesticide treatments. Nevertheless, overall, the farmers interviewed had a slightly positive opinion about the effects on yield, income and their wellbeing. In particular the reduction in pesticide treatments was perceived very positively by all respondents. Although the study finds that the majority of farmers disagreed with the recent suspension of Bt cotton cultivation by the government, it also makes clear that a thorough debate on the technology and its implementation is necessary.

Key words: genetically modified, *Bacillus thuringiensis*, biotechnology, refuge area, Bollgard II®, transgenic cotton.

[3] This chapter was based on: Edouard I.R. Sanou, Godelieve Gheysen, Bazoumana Koulibaly, Caspar Roelofs, Stijn Speelman (2018). Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso. January 2018, *New Biotechnology 42*. DOI: https://doi.org/10.1016/j.nbt.2018.01.005

2.1. Introduction

Cotton (*Gossypium* L.) is one of the most important cash crops in West Africa and is a vital catalyst to economic development in the region (Vitale et al., 2007). In Burkina Faso, despite the recent reduction in the share of export earnings for cotton in favor of gold (FAO, 2014), cotton still remains the most important agricultural crop. In fact, the cotton sector not only provides labor for more than 350,000 farmers but also indirectly contributes to the livelihood of more than 3 million people, taking into account the entire chain and that of by-products, such as local oil factories and cattle food producers.

Around the year 2000, the government of Burkina Faso became interested in Genetically Modified (GM) cotton. At that time, the cotton sector in many developing countries was facing considerable problems with pest damage (Fitt, 2000), a problem aggravated by global warming (Abate et al., 2000). This interest was stimulated by the deteriorating socio-economic situation in the cotton sector (Renaudin et al., 2012) and by the findings of Burkina Faso's National Agricultural Research Center (INERA) concerning the decreasing effectiveness of conventional chemical spraying methods (Vitale et al., 2007) and their negative environmental and health impacts.

In collaboration with Monsanto, INERA began a 5-year program of field testing of Bollgard II®, a second generation of *Bacillus thuringiensis* (Bt) improved cotton (Vitale et al., 2007). In parallel to the field testing, biosafety legislation and protocols governing regulatory oversight and approval of biotechnology products were developed by the government. Two regional Bollgard II® varieties were developed in 2008 and the Burkina National Biosafety Agency authorized these two Bt varieties for seed production and commercialization by national cotton companies. This was a significant milestone for Burkina Faso, being the first commercial use of Bt cotton in the country and the third commercial release of a GM crop in Africa (Vitale and Greenplate, 2014; Vitale et al., 2007, 2010).

However, this move was not viewed positively by all stakeholders. As in many developing countries, the debate around the adoption of biotechnology in agriculture is still ongoing and lags behind the technology uptake. The opponents of GM crops have argued that the introduction of agricultural biotechnology could threaten the survival of indigenous crops and would negatively affect biodiversity (Ezezika et al., 2012). Besides, in Burkina Faso, the lack of farmers' knowledge regarding the correct use of Bt-technology was one of the main concerns of the opponents of GM crops. Along the same lines, Renaudin et *al*. (2012), questioned the appropriateness of introducing GM cotton into the peasant production systems in Burkina Faso.

They point to the lack of information disseminated to the cotton farmers regarding management of secondary pests and the concept of refuge areas[4], which are essential aspects of this new technology. Also Vitale et al. (2010) show that this concern might be valid because farmers did not perform the recommended two late-season treatments to target the secondary pests that are not controlled by the Bt-technology.

The introduction of Bt cotton in Burkina Faso is often described as a success. For example, Vitale et al. (2008, 2010, 2011), in a series of follow-up studies, report the rapid spread (covering 70% of the cotton area), yield performance (15-20% increase), improved economic returns for smallholder farmers and the health and environmental benefits due to reduced pesticide use. Other authors, such as Renaudin et *al*. (2012) and Dowd-Uribe (2014), are more critical and state that the social and agro-ecological context of adoption is not given sufficient consideration.

Moreover, there is a growing awareness among researchers that the voice of farmers needs to be heard in the GM debate (James and Sulemana, 2014). In the light of the recent decision (James, 2016) by the Government of Burkina Faso to suspend the production of Bollgard II® cotton, and given the criticism that both the spread and suspension of Bt cotton happened in a top-down way, it is interesting to focus on the farmers' perspectives concerning this technology. In this framework, three objectives were identified. The first objective was to gauge farmers' understanding and knowledge about the concept of biotechnology and, more specifically, Bt-technology. The second objective was to assess the attitudes of farmers towards Bollgard II® and the third objective was to look at their experience with the Bollgard II® crop and their views on the decision to impose a suspension on its cultivation.

2.2. Background

Cotton was introduced in Burkina Faso in the 20th century (Perret, 2009). Over time, Burkina Faso's cotton sector has seen lots of changes, among them the liberalization of the sector (Tumusiine et al., 2014) as well as the creation of a special research program dedicated to the improvement of cotton production. Furthermore, in 1998, the National Union of Cotton Producers (UNPCB) was established in order to give farmers a voice in decision making. To

[4] To better understand the concept of refuge strategy, **Liu YB and Tabashnik BE (1997)** reported this strategy is based on the idea that refuges of non-Bt hosts plants near Bt crops provide susceptible insects to mate with resistant insects. In depth, they argued that refuges are expected to delay resistance most effectively if resistance is inherited as a recessive trait, because the mattings between homozygous-resistant and homozygous-susceptible adults produce heterozygous progeny that are killed by the Bt crops. And conversely, if resistance is not recessive and some of the heterozygous progeny survive on the Bt crop, refuges are expected to be less effective for delaying resistance (**Zhang and al., 2012**).

date, the sector is administered by a dominant parastatal company (Sofitex) and two private companies (Socoma and Faso Coton). The traditional vertical integration between farmers and companies, in which the cotton industries provide inputs, such as seeds, pesticides, fertilizers, and technical advice still exists (Theriault and Serra, 2014; Abate et al., 2000).

In 2008, Burkina Faso became the third African country, after South Africa and Egypt, to commercialize Bt crops (James, 2008). The 2008 approval and production of seeds paved the way for the planting of 125,000 ha of Bollgard II® cotton in Burkina Faso in 2009 - the most extensive single-year biotechnology launch in Sub-Saharan Africa (SSA) to date (Vitale et al., 2010). In addition, one year later, the adoption rate had already increased to 29% and by 2014 it had reached 70% or a total of 454,124 ha (James, 2008, 2014). In 2016, Pertry et al. (2016) described the Bollgard II® case in Burkina Faso as a role model for sustainable cotton production.

Bollgard II® cotton requires only two insecticide treatments to control secondary pests such as aphids and jassids. This is in contrast to conventional cotton which requires six treatments, with the initial four targeting Lepidoptera and the last two targeting secondary pests. Growing Bollgard II® cotton was expected to increase yields by up to 30% and to reduce pesticide use with positive effects on farmers' health and the environment. INERA also recommended that the cotton companies and the farmers' union (Union Nationale des Producteurs de Coton du Burkina, UNPCB) emphasize the need for effective implementation of two late-season treatments in order to guarantee yield improvement and compliance with structured refuge areas to prevent development of resistance to Bt toxins.

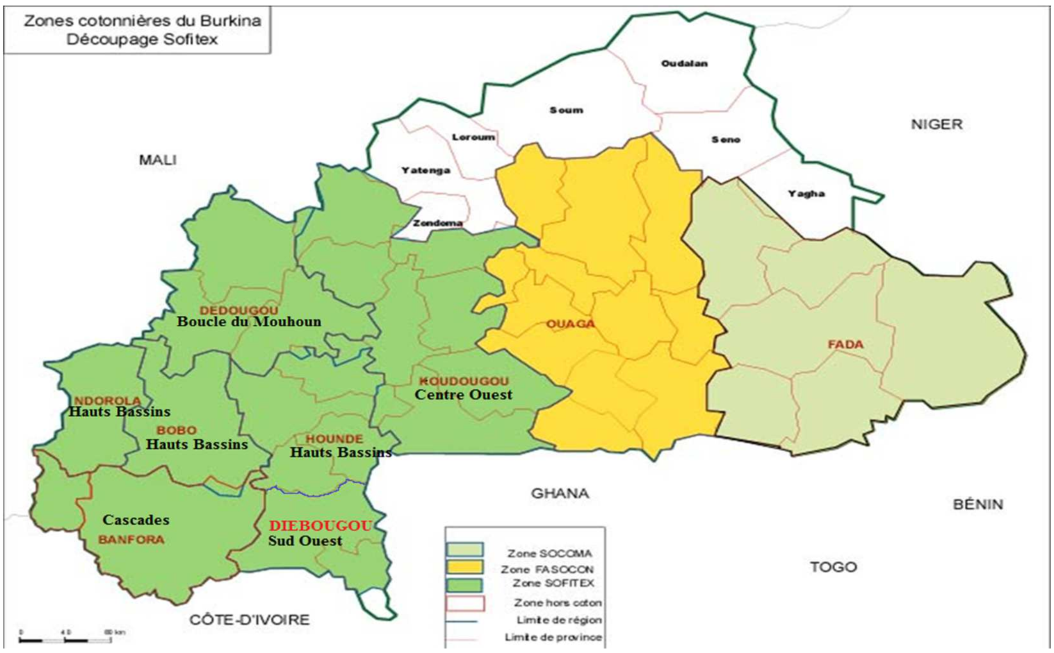
Overall, the effectiveness of Bollgard II® in terms of pest control was not questioned. There were only some concerns with respect to the financial risks for smallholders due to the high cost of the Bt seeds (Renaudin et al., 2012) or about the lack of an integrated pest management strategy by the cotton producers (Renaudin et al., 2012; Vitale et al., 2010). Nevertheless, in 2012-2013, the cotton companies reported a shorter fiber length in comparison to previous years. According to INERA, this observation was reported to Monsanto and both agreed to investigate the cause. In 2014, the use of the Bollgard II® variety was determined as the main source. In order to avoid cotton companies losing money on the international market owing to reduced fiber length, the tripartite framework (Monsanto, INERA and cotton companies) initially agreed to reduce the Bt cultivated land to 50% while trying to fix the genetic issue over a period of 3-5 years. In 2015, however, the permanent consultative framework (Association Inter-professionnel du Coton au Burkina, AICB) incorporating the government, the cotton companies and the UNPCB, urged for the suspension of Bollgard II® cotton cultivation and this decision was endorsed in 2016 by the government of Burkina Faso. This means that in 2016 only conventional seeds have been distributed by the cotton companies in Burkina Faso.

2.3. Materials and Methodology

2.3.1. Study sites and sampling design

The study was conducted during the 2015-2016 agricultural season in western Burkina Faso - an area administered by SOFITEX (Societe Burkinabe des Fibres Textiles). Sofitex is the largest of three cotton companies (see Figure 1) covering more than 85% of the cotton cultivated land and representing about 80% of the national cotton production (FAO, 2014). Three districts (Dedougou-Bobo-Diebougou) were chosen along a north-south gradient presenting different agro-climatic characteristics. These districts include 7 of the 13 Sofitex cotton ginning factories. A total of 12 villages were selected for the study (4 per district). Given that cotton farmers are organized into groups in Burkina Faso (Groupement de Producteurs de Coton, GPC) at village level, and their individual interests could differ depending on the type of farmer (Small, Medium, Large) and/or the cotton variety grown (Bt or non-Bt), the sample was designed to allow a pairwise comparison between the growers of the different varieties as well as between the types of farmer. The position occupied by farmers in their GPCs (president, active member or simple member) was also considered. In total, 324 farmers were selected. Classification of farmers was made based on the total cotton acreage grown and the number of cattle pairs used for labor.

Figure 2.1: Cotton growing zones in Burkina Faso (Sofitex, Socoma et Faso Coton)



2.3.2. Structure of the questionnaire

A questionnaire was developed based on information obtained from scientific literature (Fok, 2016; Vitale and Greenplate, 2014; Renaudin et al., 2012; Dowd-Uribe, 2014 ; Dowd-uribe & Bingen, 2011; Vitale et al., 2007, 2008, 2010, 2011; Hema et al., 2009; Vognan et al, 2002;) as well as from the official reports from the national research institute of Burkina Faso (INERA). The questionnaire focused on the appraisal of farmers' knowledge, understanding, and actual behavior towards GM cotton production in Burkina Faso, as well as on their experience based perceptions and opinions. The structure of the questionnaire is summarized in table 2.1. For instance, to gauge farmers' understanding about the use of Bt-technology, 4 statements were developed to which the farmer could answer Yes/Not sure/No. Furthermore, 7 and 3 point Likert scales were used, respectively, to measure farmers' opinions about the advantages of Bt-technology and about the recent decision to suspend Bollgard II® cotton production. Throughout the questionnaire, statements were formulated, both in positive and negative ways, in order to test the consistency of the responses given by farmers.

2.3.3. Data collection

The survey team consisted of five students recently graduated from the Rural Development Institute of the Polytechnic University of Bobo Dioulasso. The students were selected according to their previous survey experiences and their native local language (Moore, Bobo, Dioula or Dagara) to enable coverage of the predominant languages in each district. Before interviews were initiated, the enumerators were trained and exposed to the objectives of the study. Surveys were conducted using a door-to-door strategy. Individual assessment was adopted in order to avoid all external influences. Once at the farmer's home, the farmer was first informed about the purpose of the survey; then he was assured that his opinions would be kept confidential and that he did not have to represent the view of someone else. Each interview took about 45-60 minutes.

2.3.4. Statistical analysis

Data were analyzed using IBM SPSS Statistics (version 22). The data were summarized and descriptive data analysis was conducted using means, frequencies and percentages. Chi-square and one-way analysis of variance (ANOVA) were conducted to assess differences between farmer types (small, medium, large), variety grown (Bt and Non-Bt) and education level, as well as their position in the GPC (president, active member, simple member).

Table 2.1: Structure of the questionnaire

Clusters	Description	Method/tools	Target group
1. Knowledge/understanding	Knowledge about Biotechnology and Bt technology	Yes/No (6 statements)	All farmers
	Understanding on the use of Bt technology	Yes/No/Not sure (4 statements)	Type of farmers, Education level and Position in the GPC
2. Opinion/Perception			
- Effectiveness (agronomic)	Agricultural practices, pest control, labor times, etc.	True/False/Don't know (15 statements)	all farmers
- Advantages (socio-economic)	yield performance, income gain, farmers wellbeing, etc.	7 points likert-type scale (from 1=Strongly disagree,…. 4= Neutral, …to 7= Strongly agree): 7 statements	Type of farmers (Small, medium and large)
- Health and environmental	Health benefit, environmental risk, etc.	True/False/Don't know (6 statements)	all farmers
3. Behavior	How many times have farmers sprayed their cotton fields this year?	Based on the declaration of farmers (1 statement)	Bt and Non Bt growers
4. Seed cost/Decision to abandon	Did farmers know how the Bt seed price was fixed? Is this price affordable for them?	Yes/No (3 statements)	all farmers
		Yes/No (2 statements)	all farmers
	Do farmers know why this decision was undertaken? Do they agree with that?	3 point likert-type scale (Agree/Neutral/Disagree)	Bt and non Bt growers

2.4. Results

2.4.1. Basic demographic profile of farmers

All of the farmers surveyed (100%) were male and the majority were in the age groups 31-40 (39.2%) and 41-50 (43.4%) (table 2.2). Most farmers (over 80%) had not had any formal education. Only 2.8% of the selected farmers had received formal education in agriculture, 11.4% had followed primary education and 4.9% secondary. The overall experience of the selected farmers in cotton production was slightly greater than 25 years. Seven years after the introduction of Bollgard II® in Burkina Faso the farmers growing Bt had, on average, 6 years of experience with this crop, but even those not growing Bt at the time of the survey had tried it for 2 years, on average. The farmers interviewed held different positions within the GPC: President (15.7%), Active member (27.8%) and Simple member (56.5%).

Table 2.2: Basic demographic background of the farmers surveyed

Parameters	No. farmers	Percentage (%)
Age		
up to 20 years	2	0.6
21 - 30 years	22	6.8
31 - 40 years	127	39.2
41 - 50 years	141	43.4
51- 60 years	27	8.4
over 60 years	5	1.6
Education level		
Non	103	31.8
Non formal	159	49.1
Primary	37	11.4
Secondary	16	4.9
Formal agriculture background	9	2.8
Type of farmers		
up to 2 ha + 1 cattle pair (Small)	108	33.3
between 2 and 5 ha + 2 cattle pairs (Medium)	108	33.3
over 5 ha + more than 2 cattle pairs or tractor (Large)	108	33.3
Farmers Position in GPC		
President	51	15.7
Active member	90	27.8
Simple member	183	56.5
Experience		**Mean (years)**
Farmer overall experience in cotton	324	26.7
Average Bt-experience of Bt cotton growers	162	5.8
Average Bt-experience of conventional growers	162	2.4

Gender: 100% of farmers are males (N = 324)

2.4.2. Farmers' knowledge and understanding of biotechnology and Bt-technology and its use

The majority of the farmers surveyed (over 90%) presented low awareness and a poor knowledge of the core concepts of biotechnology and Bt-technology (table 2.3). Most terms and concepts appeared to be new for the majority of participants. In spite of the ongoing trials for two other GM crops (Bt maize and Bt cowpea) 97% of the farmers interviewed had not heard about any biotech crops other than Bt cotton. While the "No" respondents were the majority, a one way ANOVA was conducted to see whether this knowledge was influenced by education level. The test showed that there was a significant difference ($F(4, 319) = 215.22$, $p<0.001$). The small group of farmers with a formal agricultural education background had significantly more knowledge than those with Secondary, Primary, Non Formal and No education.

Farmers' understanding on the use of Bt-technology was tested using the four statements in Table 2.4. More precisely, the knowledge about the two late-season insecticide treatments required and on the implementation of refuge areas was tested. Nearly 60% of the selected farmers asserted that the two late-season treatments were necessary to target secondary insects, whereas 32% of participants were "not sure" versus 8% who did not know anything about this. Regarding the required timing to apply the two late-season treatments, the "Yes" respondents presented a slightly higher percentage (42.9%) than the "Not sure" group (41.1%), while 16% of farmers surveyed did not really know. As regards compliance with refuge areas, most of the farmers (over 60%) were "Not sure" what this meant and how it worked. Moreover, nearly 30% of respondents did not know anything about refuge areas. Only 8% of participants knew what it was and only 3% were able to explain how a refuge strategy should be implemented. To explore whether or not there was a difference in understanding concerning Bt-technology implementation according to farmers' positions in the GPC, a one-way ANOVA was performed. A statistically significant difference was found ($F(2, 321) = 78.34$, $p<0.001$). A post-hoc test (Scheffe test) indicated that the mean score for simple members was significantly ($p<0.001$) lower than that of presidents and active members. Presidents and active members did not differ significantly ($p = 0.946$). The overall mean score for respondents was 0.29 (SD = 2.08 , 95%CI = 0.06, 0.22).

2.4.3. Farmers' perceptions about Bt-technology effectiveness in cotton production

To appraise farmers' perceptions about the effectiveness of Bt-technology, fifteen statements (table 2.5) were designed around three keys points: agricultural practices, pest control and field management. The questions were formulated both as positive and negative statements comparing Bt and non-Bt cotton. Results show that farmers did not adjust agricultural practices when growing Bollgard II® cotton except for insecticide use. Over 95% indicated that they did not change input quantities (fertilizers, herbicides, labor etc.). Farmers agreed, however, that the quantity of insecticides used in Bollgard II® cotton production was reduced. In addition, the efficacy against lepidopteran insects is illustrated by the affirmation of the farmers that they never resort to any additional insecticide treatment to target these insects. Similarly, most farmers confirmed that Bollgard II® plants resisted lepidopteran insect attacks. Furthermore, the farmers interviewed stated that Bollgard II® cotton plants carry and retain more capsules than conventional cotton due to their resistance to lepidopteran insects. Overall, the majority of farmers expressed their satisfaction concerning the elimination of the first four pesticide treatments.

2.4.4. Farmers' opinions concerning Bt-technology

Farmers' opinions about Bt-technology across three farmers' groups (small, medium, large) are reported in Table 2.6. Regarding the positive yield performance, small scale farmers are least convinced that Bt cotton increases production (M=4.96, SD=0.864) compared to medium size farmers (M=5.84, SD=0.877) and large scale farmers (M=6.05, SD=0.741). Asking whether yield performance generated an income gain or not, small scale farmers partially agreed (M=4.81, SD=0.855), whereas both medium size (M=5.81, SD=0.755) and large scale farmers (M=5.87, SD=0.628) agreed on the increase in income. In addition, small scale farmers, on average, partially agreed that Bollgard II® cotton production improved their livelihood, living conditions and allowed them to increase their acreage due to the income gain. Medium and large scale farmers were slightly more positive about these effects. Moreover, farmers were asked whether Bollgard II® cotton growing enabled them to increase their land surface cultivated with cereals and to recover their debts from the cotton companies. The small scale farmers were, on average, neutral towards this, whereas both medium and large scale farmers were more positive and partially agreed. In order to test the hypothesis that farm size (small, medium, large) could have an effect on the level of satisfaction (using a scale from 1: Strongly disagree to 7: Strongly agree), ANOVA was performed[5]. This found a statistically significant effect $F(2, 321) = 22.189$, $p<.0001$). To further evaluate the nature of the difference between the three farm sizes, three Scheffe post-hoc tests were conducted. The mean score for small scale farmers (M = 5.08, SD = 0.41, 95%CI = 4.99, 5.05) was found to be significantly ($p<.0001$) different from that of medium size (M = 5.44, SD = 0.54, 95%CI = 5.34, 5.55) and large scale farmers (M = 5.46, SD = 0.47, 95%CI = 5.37, 5.55). Medium and large scale farmers did not differ significantly ($p = 0.976$). The overall level of satisfaction in the sample was 5.21 (SD = 0.57, 95%CI = 5.1, 5.3) reflecting that farmers have a partially positive attitude.

2.4.5. Farmers' opinions regarding the health and environmental effects of growing Bollgard II® cotton

Based on the lower use of pesticides in Bollgard II® cotton cultivation, six statements were developed to capture farmers' opinions about health and environmental risk management. A combination of positive and negative statements was used. Outcomes reported in table 7 revealed that all respondents agreed entirely with the first three statements. They agreed that the reduction in pesticides used was beneficial for health; that it greatly reduced the burden of spraying and that, at the same time, it protected water sources. A large majority of the farmers also agreed that growing Bollgard II® did not constitute a threat to their livestock and that the presence of bees, termites and ants increased in their fields.

[5] First the assumption of homogeneity of variances was tested and satisfied based on the Levene's F test, $F(2, 321) = 0.395$, $p = 0.674$.

Table 2.3: Farmers' knowledge towards Biotechnology and Bt technology core concept

Statements	Yes		No	
	N	%	N	%
Q1. Have you ever heard about Biotechnology concept In agriculture?	31	9.6	**293**	**90.4**
Q2. Do you know that Biotechnology is a product of molecular biology based on gene manipulation and can be applied in agriculture improving local varieties?	11	3.4	**317**	**96.6**
Q3. Do you know that Bt cotton is a biotechnology variety?	31	9.6	**293**	**90.4**
Q4. Have you ever heard about another biotechnology crop other than Bt cotton?	7	2.2	**317**	**97.8**
Q5. Do you know that Bollgard II (Bt cotton variety) has been obtained by introducing a *Bacillus thuringiensis* gene into your local varieties (FK37 and SAM 59)?	20	6.2	**304**	**93.8**
Q6. Do you know that *Bacillus thuringiensis* is a bacteria and its gene gives power to plant to naturally defend itself against lepidopteran insect group in cotton production?	9	2.8	**315**	**97.2**

The highest scores are given in boldface. Cronbach's alpha = 0.828

Table 2.4: Farmers' understanding of Bt technology use

Statements	Yes		Not sure		No	
	N	%	N	%	N	%
Q7. Before growing Bollgard II, have you any idea about the number of spray targeting secondary insects? If yes, how many?	**192**	**59.3**	105	32.6	27	8.3
Q8. At what stage of the production you may apply the 2 late-season sprays?	**139**	**42.9**	**133**	**41.1**	52	16
Q9. Before growing Bollgard II, have you any idea about refuge area management intended to prevent lepidopteran insects' resistance?	26	8	**202**	**62.3**	96	29.6
Q10. Do you know how refuge area work?	12	3.7	**212**	**65.4**	100	30.9

The highest score are given in boldface. Cronbach's alpha = 0.859

Table 2.5: Farmers' perception about Bt technology effectiveness

Statements	TRUE		FALSE		Don't Know	
	N	%	N	%	N	%
Q11. Bt cotton production requires the same in inputs quantity in term of mineral and organic fertilizers like in conventional cotton production.	**319**	**98.5**	2	0.6	12	3.7
*Q12. Bt cotton production changes my current agricultural practices such labor, sowing, weeding, etc.).	-	-	**312**	**96.3**	12	3.7
*Q13. Bt cotton increases my manpower (internal and/or external) compared to conventional cotton production.	-	-	**312**	**96.3**	12	3.7
*Q14. Since I grow Bt cotton, the quantity of insecticides used doesn't change.	-	-	**322**	**99.4**	12	3.7
Q15. Except the reduction of the number of sprays, Bt cotton production does not present any difference compared to conventional cotton.	**312**	**96.3**	**-**	-	12	3.7
*Q16. Bt seeds present a weak rate of germination compared to conventional cotton	2	0.6	**312**	**96.3**	10	3.1
Q17. Since I grow Bt cotton, the shedding of capsules attributed to lepidopteran insects attack has utterly disappeared.	**312**	**96.3**	**-**	-	12	3.7
Q18. Since I grow Bt cotton, my cotton plants retain more capsules owing to the absence of lepidopteran insects attack.	**312**	**96.3**	1	0.3	11	3.4
*Q19. Bt cotton presents a long cycle of production comparing to conventional cotton.	-	-	**315**	**97.2**	9	2.8
Q20. Since I cultivate Bt cotton, I do not observe lepidopteran insects attacking and damaging my cotton field.	**312**	**96.3**	**-**	-	12	3.7
*Q21. Since I grow Bt cotton, sometimes I use more than 2 sprays because of lepidopteran insect attack.	-	-	**312**	**96.3**	12	3.7
Q22. I agree that the Bt cotton variety that I grow resists quite well lepidopteran insects attack.	**312**	**96.3**	**-**	-	12	3.7
Q23. By cultivating Bt cotton I save much labour time due to the reduction of the number of sprays (2).	**321**	**99.1**	**-**	-	3	0.9
*Q24. Bt cotton field management is more painful compared to conventional cotton	-	-	**315**	**97.2**	9	2.8
Q25. With Bt cotton, the painfulness due to spraying machine carrying is quite reduced.	**321**	**99.1**	-	-	3	0.9

(*) Questions formulated in an opposite way. The highest scores are given in boldface. Cronbach's alpha = 0.962

Table 2.6: Farmers' opinions about Bt technology advantages

Statements	Small (N=108)		Medium (N=108)		Large (N=108)	
	Mean	SD	Mean	SD	Mean	SD
Q26. Since I grow Bt cotton, yield increases in comparison to conventional cotton growing.	4.96	.864	5.84	.877	6.05	.741
*Q27. Since I grow Bt cotton, my income gain is increasingly getting lower.	4.81	.855	5.81	.755	5.87	.628
Q28. Since I cultivate Bt cotton, my livelihood has been improved owing to the high income.	5.20	.707	5.36	.779	5.40	.896
*Q29. Bt cotton growing doesn't allow me improving my living conditions.	4.93	.680	5.34	.699	5.33	.684
Q30. With Bt cotton, my income gain helps me increasing my cereals cultivated surfaces.	4.31	1.073	5.19	.990	5.20	.925
*Q31. With Bt cotton, my GPC use to face difficulties to cover debts of cotton companies.	4.04	.669	5.10	.785	5.02	.736
Q32. The income generated in Bt cotton production allows me to gradually increase my land.	4.81	1.104	5.49	.791	5.48	.742

Statements marked with an asterisk were coded in the opposite direction because disagreement with such statement means a positive opinion towards Bt-technology. Cronbach's alpha = 0.752. On a scale from 1=Strongly disagree to 7=Strongly agree. SD: Standard Deviation. N: number of farmers

Table 2.7: Farmers' opinions regarding health and environmental saving by growing Bt cotton

Statements	TRUE		FALSE		Don't Know	
	N	%	N	%	N	%
*Q33. Reduction of number of sprays does not present any effect on my health.	-	-	**324**	**100**	-	-
Q34. Since I grow Bt cotton, my pains after sprayings are abated because of less sprays.	**324**	**100**	-	-	-	-
*Q35. Less use of insecticides doesn't protect our water sources.	-	-	**324**	**100**	-	-
Q36. By cultivating Bt cotton, we reject less pesticide containers in the environment.	**322**	**99.4**	-	-	2	0.6
*Q37. Bt cotton fields present a threat for my livestock feed.	2	0.6	**321**	**99.1**	1	0.3
Q38. Since I grow Bt cotton, I use to observe in my field bees, termites and ants.	**320**	**98.8**	2	0.6	2	0.6

(*) Questions formulated with negative effect. The highest scores are given in boldface. Cronbach's alpha = 0.762

2.4.6. Farmers' behavioral practice in pest control management

The introduction of Bt cotton in Burkina Faso has eliminated the first four treatments targeting lepidopteran insects. However, the two late-season treatments against secondary insect attacks are still required. Table 2.8 outlines farmers' pest management practices. Based on farmers' declarations regarding how many times they sprayed during the ongoing agricultural season, more than 80% of the growers (Bt and Non-Bt) confessed that they sprayed their cotton fields less than the number of times recommended by INERA. The majority (71%) of Bt growers sprayed once, whereas 75% of conventional farmers sprayed three times. The proportion of farmers who applied the recommended number of treatments was respectively 19% for Bt and 6% for Non-Bt growers.

Table 2.8: Farmers' behavioral practice in pest control management

Farmer type	Variety	Number of Sprays						
N=324	N=324	0	1	2	3	4	5	6
Small	Bt (n=54)	16	**32**	6				
N=108	Non-Bt (N=54)		1	9	**44**			
Medium	Bt (n=54)		**42**	12				
N=108	Non-Bt (N=54)			4	**41**	6	2	1
Large	Bt (n=54)		**41**	13				
N=108	Non-Bt (N=54)				**37**	4	4	9
Total	Bt (%)	9,9	**71**	19.1				
(%)	Non-Bt (%)		0.6	8	**75.3**	6.2	3.7	6.2

*Chi square small (3) = 89.7, p<0.001*Chi square medium (5) = 96, p<0.001 *Chi square large (5) = 108, p<0.001*Chi square total (6) = 283, p<0.001. The highest scores are given in boldface

2.4.7. Farmers' opinions about Bt seed cost and the decision to forsake Bollgard II® cotton

During the surveys, the Bt seed price ($45/ha) was mentioned by the majority of the farmers as the main constraint for the adoption of Bt cotton. To collect farmers' opinions about the current price, three statements were developed. The first was to see whether they knew how the price was fixed; then they were asked to respond whether or not the Bt seed cost was affordable. The last statement sought to understand whether the current Bt seed cost enabled their GPC to cover the debts from cotton companies at the end of the agricultural campaign. According to the cotton companies, the Bt seed price is fixed with the agreement of UNPCB based on the following formula: (Non-Bt seeds + 6 sprays) cost = (Bt seeds + 2 sprays) cost. In this way, the higher price of Bt is offset by the elimination of four treatments. The results in Table 2.9 showed that 91% of the farmers had no idea about this formula. Furthermore, 90% of the participants judged that the current price is unaffordable. As to the last statement, a contradictory view emerged, with 56% of respondents agreeing and 44% disagreeing.

As described above, cotton companies first began reducing Bt cultivated land to 50% in the 2015-2016 rainfall season, followed by its complete suspension in 2016-2017. To assess farmers' opinions regarding those decisions, participants were first asked whether they knew why the Government envisaged abandoning Bt cotton. A 3 point Likert-type scale (Agree/Neutral/ Disagree) was used to collect farmers' views about the decision to suspend Bollgard II® cotton. The majority of the farmers interviewed (90.7%) stated that they were surprised at the beginning of the 2015-2016 agricultural campaign when the cotton companies decided which GPCs had to stop Bollgard II® cultivation. Similarly, slightly more than 90% of the participants indicated that they had no idea about the reasons that led to the decision to abandon Bt cotton. Subsequent to the limited knowledge about the reasons behind the decision to suspend Bollgard II® cotton, shown in our surveys, 88% of respondents disagreed with the decision to suspend Bt cotton, whereas 10% remained neutral versus less than 2% who agreed.

Table 2.9: Farmers' opinions about the decision to forsake Bt cotton

		1*	2*	3*
Bt Growers	N	3	15	**144**
	%	1.85	9.3	**88.9**
Non-Bt Growers	N	2	17	**143**
	%	1.2	10.5	**88.3**
Total	N	5	32	**287**
	%	1.5	9.9	**88.6**

The highest scores are given in boldface.1*=agree, 2*=Neutral, 3*=disagree
*Chi square (2) = 0.328, p = .849

2.5. Discussion

The farmers in this study showed poor knowledge concerning the core concepts of biotechnology and Bt-technology. A similar observation of a very poor understanding, awareness and knowledge among farmers was also made by Lewis et al. (2010) in Tanzania concerning GM technology and terminology. Despite the involvement of UNPCB throughout the Bt cotton introduction process, and despite 7 years of experience with Bt cotton, many farmers were still unaware of the need to install refuge areas. However, the study found that farmers' understanding towards Bt-technology implementation in cotton production was strongly affected by the position they occupied in their GPC. Indeed, results revealed that presidents and active members of the GPC had an average knowledge while a large majority of the simple members were ignorant about the use of Bt-technology. This observation could be related to the cotton production system and service extension system in Burkina Faso. Due to the high number of GPCs (over 12,000), the training for farmers in field management is organized at departmental (or provincial) level and covers at least five villages, thus including more than 200 GPCs. Therefore, only the presidents and/or some active members attend this awareness training. In theory, the participants should update farmers who did not get the chance to participate. The same operating mode was used with the implementation of Bollgard II® cotton, with no changes, in spite of the recommendation by INERA urging emphasis on the two late treatments to target secondary insects and on compliance with the refuge strategy.

During the field visits, cotton companies' fieldworkers, commonly known as ATC (Agent Technique Coton) were also interviewed. They are elected to assist and monitor producers' field management. It was striking that most of them could not explain how the implementation of refuge areas works. Some who gave a correct explanation confessed that it was quite difficult to implement the refuge strategy without first changing farmers' behavior based on their current agricultural practices. Stone (2011) warned that, in Warangal in India, the overall income gains from Bt cotton could be undermined by the widespread lack of understanding and practical implementation of refuges by farmers. The same was reported by Kruger et al. (2012) in the context of Bt maize introduction in South Africa.

Our data also seem to suggest that the cotton companies in Burkina Faso gave insufficient support to the farmers with respect to Integrated Pest Management (IPM) strategies. As a consequence, the majority of the farmers surveyed, over 80% of both Bt and conventional cotton growers, do not respect the guidelines put forward by INERA in terms of spraying. In his research looking at the 2009-2010 season, Renaudin et al (2012) also found relatively low compliance with the recommendations among Bt growers, with 40% following the recommendations and an average spraying frequency of 1.1. Such low compliance was reported by Vitale et al. (2010) as a thread for both yield and economic performance in Bollgard II® cultivation. In his study, conventional farmers, however, sprayed 5.7 times, on average, with 81 % applying the six recommended treatments (Renaudin et al., 2012). This has changed drastically in our study, where less than 10% of the conventional farmers comply. There might be several reasons for this. One reason might be the existence of spillover effects due to a change in pest dynamics and pressure caused by the high coverage of Bt. Such effects have also been reported in other studies (Hutchinson et al., 2010; Wu et al., 2008). Another reason could be that farmers are reluctant to revert to spraying six times[6]. Discussion with farmers on the decision to suspend cultivation of Bt seems to confirm this, as many farmers claim that they will no longer apply the six recommended sprayings. Moreover, they feel that the spraying calendar, which recommends spraying every two weeks from the beginning of the seedling stage, is not sufficiently flexible.

Even after eight years of experience with Bollgard II® cotton, the majority of farmers claim that the right timing for the two late-season sprays is unclear and a large majority are unaware of the importance of the refuge areas. These observations support the claim made by Renaudin et al. (2012) concerning the appropriateness of the introduction of Bt-technology into the farming system of Burkina Faso given the lack of information dissemination to the cotton farmers. In the long term, this will certainly have adverse effects and will negatively influence Bollgard II® cotton yield performance. Similarly, the importance of pest management practices was shown in a study by Berlin's Ecologic Institute (Kaphengst et al., 2011). Reviewing 721 case studies and comparing the yield performance of GM crops with conventional crops, they show that the highly different results in different countries can mostly be attributed to this. Recent studies in Benin (Sinzogan et al., 2004), Kenya (Midega et al., 2012) and Pakistan (Khan and Damalas, 2015) show that efficient integrated pest management remains a challenge, both in Bt and conventional cotton production. All these studies attribute this to the insufficient knowledge of farmers concerning the implementation of integrated pest control strategies.

The farmer's point of view on the social impacts of Bollgard II® cotton has also been tackled in this study, looking at aspects such as social wellbeing, economic resilience and environmental integrity. The opportunity to reduce pesticide quantities by two-thirds was cited as the main reason by the majority of farmers to explain the rapid adoption of Bt-technology. The technology not only improved their own wellbeing in terms of health, but also reduced the pesticide burden upon the environment. Furthermore, yield gains were also reported. This is in line with studies by Vitale et al. (2010, 2011, 2014). The same conclusion was reached by Renaudin et al. (2012), who also highlighted the increased financial risks for smallholders due to the high cost of the Bollgard II® seeds. This study showed that the level of satisfaction of

[6] It is important to note that most of the farmers growing conventional cotton in our sample also have experience with growing Bt. This is related to the top down distribution of seeds by the cotton companies in Burkina Faso, which decide annually which type of seeds are distributed to each GPC.

farmers regarding Bt-technology depends on the type of farmer (small, medium, large). While large and medium sized farmers tended to be largely positive, small scale farmers were more neutral. This finding of differential effects is in line with past studies in other countries. For instance, Subramanian and Qaim (2009) in India also indicated that greater benefit is generated by larger farms and Arza et al. (2013) demonstrated that, in Argentina, smallholders become increasingly reliant on middlemen with the introduction of Bollgard II® cotton, reducing the benefit. In contrast, Bennet et al. (2004, 2006), in South Africa, found that smallholders obtain greater economic benefits from growing Bt cotton than farmers with more land. In Australia, Sanchez (2015) showed that, due to successful pest management, benefits are shared by the different groups of farmers. Fischer et al. (2015) reviewed 99 case studies and showed how the economic impacts of GM cotton adoption for different groups of farmers were very mixed and that the political and regulatory context had a significant impact on the ability of different groups of farmers in different locations to benefit. Specifically in Burkina Faso, the results from the previous studies did not specify differences between farmer groups (Vitale et al., 2008, 2010, 2011, 2014).

The high seed cost was perceived by the majority of the farmers as the main constraint affecting the economic benefit of Bt cotton. While Renaudin et al. (2012) demonstrated how economic benefit for small scale farmers was impacted because of the extra seed cost in producing Bt cotton, Vitale et al. Vitale et al. (2010, 2011, 2014), in contrast, estimated that the higher seed costs for Bt were offset by the elimination of four treatments. As a consequence, they found no significant difference between production costs for Bt and conventional cotton. Subject to an in-depth investigation, our study notes that the higher seed cost for Bt will affect profitability. This is because nearly all farmers surveyed recognized that the recommended 12kg of seeds per hectare for Bollgard II®, and even the 30 kg for conventional cotton, are insufficient. Therefore, they always use extra seed to overcome the lack of germination due to rainfall irregularity at the beginning of the sowing period. As a result, farmers used at least 1.5 bags of seeds (bag of 12 kg or 30 kg) instead of one bag (as advised) to sow one hectare.

Finally, the decision to suspend Bollgard II® cotton production in Burkina Faso was evaluated. It was shown that farmers and the government did not share the same point of view. As described above, in 2016, the issue of shorter fiber length for Bollgard II® cotton had already been known for some years, and the cotton companies and the Burkina Faso government were losing money on the international market. It should be noted that this did not translate into financial problems for farmers, as the Bollgard II® cotton farmers were rewarded according to the harvested yield. A breeding plan developed by INERA to maintain Bollgard II® whilst trying to resolve the issue together with Monsanto, in order not to disorient farmers in their current practices because of the familiarity created with Bollgard II® cotton, failed to convince the other stakeholders (cotton companies, AICB and the government). Therefore, the short term proposition by INERA to progressively reduce Bollgard II® cultivated land was only followed for one year (2015-2016). After that, the decision was taken to abandon Bollgard II® cotton. During our surveys, some farmers claimed that, due to the decision to reduce the area cultivated with Bollgard II®, they were obliged by cotton companies to grow conventional cotton against their will. As a consequence, certain farmers obtained Bollgard II® cotton seed from their friends in neighboring villages and mixed Bt and conventional cotton on the same plots. This shows that such a ban, opposed by the farmers, might result in situations such as that described by Fischer et al. (2015) in Argentina and India where uncertified Bollgard II® cotton seeds of dubious quality circulated on the market. There is a risk of the proliferation of a black market for seeds, as has happened for mineral fertilizers and herbicides.

2.6. Conclusion and recommendations

This study focused on the perceptions and opinions of farmers in Burkina Faso concerning the cultivation of Bollgard II® cotton. Five main results can be highlighted:

Knowledge of farmers concerning biotechnology and Bt-technology is limited and depends on their education level and their role within the GPC. The differences in knowledge are furthermore consolidated by the operating mode of the cotton companies, which does not involve simple members of GPCs in the awareness training provided by the fieldworkers from the cotton companies. As a result, not all information seems to trickle down.

The regulatory oversight of the implementation of Bt-technology is inadequate. This is illustrated by the lack of compliance with prescriptions concerning structured refuge areas. The risk of the non-implementation of the refuge strategy was ignored by both farmers and fieldworkers.

Farmers' compliance with recommended pest management strategies is low. Several farmers, for example, stated that Bollgard II® cotton does not require any treatment: "the main problem in cotton production is lepidopteran insects. So, with Bollgard II® cotton we don't need any insecticide treatments because the damage from secondary insects is not important". The specific recommendation for two late insecticide applications to control aphids and jassids was only implemented by 19% of Bollgard II® cultivators. In contrast to earlier studies, the compliance of farmers growing conventional cotton with the recommended six sprayings was extremely low. Further research needs to be conducted to explain this trend.

Even though different appreciation levels for the income gain generated by Bollgard II® cotton adoption were observed between farmer groups, the study found that the majority of farmers were satisfied. However, the main constraint underlined by the farmers was the perceived seed cost. Most farmers do not realize that production costs are kept the same for conventional and Bollgard II® cotton, as some of the insecticide cost (in terms of the four early applications that are not needed) is included in the seed price for Bollgard II®. Investigation into the Bt seed pricing policy revealed that there was a greater divergence between the farmers' organizations and their base membership. While cotton companies stated that farmers are involved in the pricing strategy through their national union, farmers on the ground were unaware of what was decided and where the decision came from. This observation highlights the need to reinforce a mode of communication which would enable farmers to be regularly updated.

Finally the decision to suspend Bollgard II® cotton in Burkina Faso was perceived to be bad by the majority of the farmers. Cotton producers are being paid for the cotton produced and they dislike the fact that four extra insecticide treatments will be needed once more and that the result will be a reduction in yield, and thus reduced income. There is a high risk that the majority of farmers will not respect the treatment guidelines for the production of conventional cotton and this is in the context of cotton production already characterized by a lack of integrated pest management.

To conclude, while the experience of Burkina Faso was perceived as a sustainable agricultural model, the adoption of Bt cotton in Sub-Saharan African (SSA) countries is now being hampered due to the ongoing debate around the quality of Bollgard II® fibers. However, to guarantee the success of Bt cotton in the farming system of Burkina Faso, after having fixed the fiber length issue, dissemination of knowledge needs to be improved, as highlighted by Renaudin et al (2012). This extends to the general role of the government to create public awareness about biotechnology. Furthermore, to understand the gap between, for example, knowledge about pest management and compliance, adoption of a new multidisciplinary assessment approach will be required, taking into account parameters such as farmers' behavior. As Dowd-Uribe (2014) writes (2014), throughout its evaluation it is crucial to focus on how this technology is embedded within a social and agro-ecological context. This will allow greater understanding of the impacts.

Chapter 3: What kind of biotechnology do farmers prefer? A Discrete Choice Experiment Approach considering Cotton Cultivation in Burkina Faso[7]

Abstract

While a fierce debate about the advantages and disadvantages of GMOs is ongoing, it is surprising that farmers are often not consulted. In Burkina Faso, where Bollgard II® cotton was commercially released in 2008, studies highlight that cotton producers are in general satisfied with the reduction in insecticide use, while the economic benefits are a source of controversy. The objective of this chapter is to get insight into farmers' preferences towards attributes in cotton cultivation. For this purpose a Discrete Choice Experiment (DCE) was developed. Five key attributes were identified to describe improved cotton varieties: Seed development and provenance, Seed costs, Yield, Required number of insecticide sprays, and preservation of agricultural practices. Farm-gate surveys were conducted among 324 cotton farmers in Western Burkina Faso. The results show that overall farmers have a positive preference towards yield improvements and a negative preference towards pure private seed development and towards an increase in the requested number of insecticide applications or in the seed costs. According to their current varieties (Bt and non-Bt), a difference was observed regarding their preferences for the status quo situation, indicating that Bt growers have a stronger preference to keep growing their current variety than non-Bt farmers. When dividing the sample in segments based on the farm size, it was shown that there were different preferences with respect to the development of the variety and the required number of insecticide applications. Overall it can be concluded from this study that economic benefits (linked to higher yields , lower seed costs or reduced pesticide use) shape farmer's preferences.

Key words: GMOs, Bollgard II®, Bt cotton, Discrete Choice experiment, Conditional Logit Model, Farmers, Burkina Faso.

[7] This chapter was based on: Edouard I. R. Sanou, Juan Tur-Cardona, Jeffrey D. Vitale, Bazoumana Koulibaly, Godelieve Gheysen, Stijn Speelman. "What kind of biotechnology do farmers prefer? A Discrete Choice Experiment Approach considering Cotton Cultivation in Burkina Faso". *In International Journal of Agricultural Sustainability. (under review)*

3.1. Background and Introduction

The adoption of Genetically Engineered (GE) crops in Sub-Sahara Africa (SSA) is highly controversial (Dowd-uribe & Bingen, 2011; Obonyo et al., 2011). Although several authors claim that agricultural biotechnology presents an opportunity to alleviate starvation and poverty, malnutrition and food insecurity (Lokko et al., 2018; Okeno et al., 2013; Ruane & Sonnino, 2011; FAO, 2009), the adoption of Genetically Modified (GM) crops is lagging behind in SSA compared to other parts of the world (ISAAA, 2017; Vitale et al., 2007, 2011).

Burkina Faso is an exception to this. Already in 2008 Bollgard II® cotton was commercially released in Burkina Faso. Evidence of the first five-years of Bt cotton commercialization in Burkina Faso positioned its positive experience as a roadmap for eventual wider adoption of GMOs in Africa (Vitale & Greenplate, 2014) and as a success model towards sustainable agriculture practices (Pertry et al., 2016). Also FAO (2010) followed the experiences of Burkina Faso with interest due to the particular dominating position of smallholders in the agricultural sector.

Various studies on the commercialization of Bollgard II® in the Burkina Faso farming system have been mostly positive about the outcomes (Fok, 2016; Vitale & Greenplate, 2014 Vitale, Ouattarra, & Vognan, 2011; Vitale et al., 2010). The majority of the studies focusing on the experience with Bt cotton in Burkina Faso, whether using ex-ante (Vitale, et al., 2008, 2007; Renaudin, Pelc, & Opois, 2012) or ex-post approaches (Dowd-Uribe, 2014; Fok, 2016; ; Renaudin, Pelc, & Opois, 2012) focused on the overall economic benefit based on the overall yield gains and the production cost comparing to conventional cotton. However, the potential economic benefits of the GM technology for small farmers' welfare is still debated studies (Brookes & Barfoot, 2016; Subramanian & Qaim, 2010; Edmeades & Smale, 2006), due to the higher seed cost of Bt-cotton (Renaudin, Pelc, & Opois, 2012; Dowd-Uribe, 2014) specially being the case of poor farmers.

Recently, Sanou et al. (2018) investigated farmers opinions towards Bt cotton in Burkina Faso pointing that small or subsistence farmers (which dominate the cotton sector of Burkina Faso) were not entirely positive about the economic benefits of Bollgard II® mainly because of the seed pricing policy. These results seem to support the concern that the developed variety might not entirely match with farmers' expectations. Along the same line it also has been noted by e.g. Carro and Astier (2014) that while smallholder producers are the ones most likely to be affected by the introduction of GM crops, they are least included in public debates and consultation about the development, implementation or regulation of this agricultural biotechnology. Also in Burkina Faso where the cotton value chain is organized in a very top-down manner, farmers' involvement in the development and spread of the crop has been limited.

In this context this article particularly focuses on farmers preferences for key attributes for improved cotton varieties. A Discrete Choice Experiment (DCE) considering different hypothetical GM varieties was used to assess which traits farmers would value more. Following Breustedt, Muller-Scheeßel, & Latacz-Lohmann (2008), there is relatively little empirical evidence in literature on farmers' preferences for GM technology using a DCE (e.g. Krishna & Qaim, 2007; Kolady & Lesser, 2006; Qaim & Janvry, 2003; Hubbell, Marra, & Carlson, 2000). And, to the best of our knowledge, a DCE approach has been seldom accounted for in gaging farmers preferences towards GM technology in SSA apart from this recent ex-ante study (Chinedu et al., 2018).

This study is organized in 3 sections. First, the approach as well as the method adopted to perform the DCE is explained. Secondly the outcomes from the DCE analysis are presented and discussed. Finally in the last section some conclusions are made.

3.2. Cotton Cultivation in Burkina Faso

Cotton is the most important cash crop in Burkina Faso. The cotton sector not only provides labor for more than 350,000 farmers, but also indirectly contributes to the livelihood of more than 3 million people, taking into account the entire value chain and that of by-products, such as local oil factories and cattle food producers (FAO, 2014). The cotton production chain in Burkina Faso is administrated through a vertical integration between farmers and cotton companies in which the cotton companies provide inputs, such as seeds, pesticides, fertilizers and technical advice to the farmers, who later sell their cotton to the company at a guaranteed price (Méda et al., 2018; Theriault & Serra, 2014; Tumusiime, Brorsen, & Vitale, 2014). In 2008 Burkina Faso adopted two transgenic insect-resistant varieties developed through a collaboration between Burkina Faso's National Research Institute and Monsanto corporation (Vitale et al., 2008, 2007). Seven years later, due to a quality issue faced by cotton industries related to the fiber lint, the two varieties were withdrawn from the national market (James, 2016). At this moment, the quality issue discussion is still ongoing, , with the perspective to fix the backcross issue pointed as non-sufficient to ensure the carry-over of the desired beneficial traits (Dowd-Uribe & Schnurr, 2016).

3.3. Discrete choice in cotton cultivation

3.3.1. Sampling Method

Given that an individuals' perception of the risk and benefits of a new technology is determined by selected sources of information, values, interests and individual experiences (Slovic, 2000), our surveys were conducted with household heads at the farm-gate. A total of 324 farmers were interviewed across three regions in the west of Burkina Faso, , an area administered by Sofitex. Sofitex is the largest of three cotton companies covering more than 85% of the land cultivated with cotton and representing about 80% of the national cotton production (FAO, 2014). The regions (Dedougou, Bobo et Diebougou) involved in this study were purposely identified along a north-south gradient presenting different agro-climatic characteristics. These are known to be determinant factors influencing cotton production in Burkina Faso (Dowd-Uribe, 2014).

A stratified sampling method was adopted in the selection of farmers to interview. This stratification (table 3) relied on two key features type of variety currently grown and type of farmer. Farmers growing conventional or Bt varieties have different yields, experience and will have to implement different farming practices that might influence preferences. Also, owing to the discontinuity observed per regions and villages, we decided to look for the type of farmers according to the size of plots previously defined by INERA (small, medium and large). Within each stratum a similar number of farmers were randomly selected. Table 1 shows a comparison of the socioeconomic characteristics of the selected types.

3.3.2. Discrete Choice Approach

Choice Experiments (CE) have been widely used in the agricultural and environmental economics literature and their use in development economics is rising (Ortega, Waldman, & Richardson, 2016; Solino et al., 2014). Several studies have used CE to evaluate farmers' behavior and preferences (Gelaw, Speelman, & Van Huylenbroeck, 2016; Ortega, Waldman, & Richardson, 2016; Schreiner & Latacz-Lohman, 2015). An advantage of using CE is that it is a technique for eliciting preferences to understand farmers' demands for new varieties where it is impossible to use revealed preference data on the actual choices made by farmers. In our study, the CE performed embodies the adoption of a Genetically modified crop. The crop considered is an insect resistant cotton variety. Farmers choose between different alternatives involving GM variety attributes, according to their own preferences and budget constraints. The data from the CE are analyzed using a Conditional Logit (CL) model.

Econometrical Model

The conditional logit model originates from random utility theory. A farmer *i* faces J choices, including others alternatives or keeping his status quo. Suppose that the utility level of choosing alternative j for this farmer is (Louviere et al., 2010):

$$U_{ij} = \beta' X_{ij} + \varepsilon_{ij} \qquad (1)$$

where Xij is a vector of choice-specific attributes. For the conditional logit, the parameter β is constant across choices. A farmer chooses scenario j, if the utility Uij is the highest among all J choices (i.e., Uij >Uik for all k ≠ j). To extend the CL model, an additional error ε_{ij} is incorporated into the model to capture any remaining Status Quo (SQ) effects in the stochastic part of utility (Scarpa, Ferrini, & Willis, 2005). Thus, when choice j is made, the statistical model for the probability between alternatives i and j can be represented as:

$$P(y_i = j) = P(U_{ij} > U_{ik}) \; \forall \; k \neq j \qquad (2)$$

Following Bonnichsen and Ladenburg (2015), an addition of an Alternative Specific Constant (ASC) for the SQ, reduces the *Status Quo bias* and improves the internal validity of the stated preferences. In principle, the respondents thus only make trade-offs with regards to the attributes and potential *Status Quo* effects are cancelled-out as it enters the utility function for the entire alternatives (Meyerhoff & Liebe, 2009). The observable component X_{ij} is assumed to be a linear function:

$$X_{ij} = ASC + \alpha_m Y_{mj} \qquad (3)$$

Where α denotes a vector of preference parameters associated with attribute m, Y_{mj} a vector of attributes of alternative j and ASC denotes an alternative specific constant. The ASC for the SQ alternative is a dummy variable that controls for the utility associated with the SQ alternative relative to the hypothetical alternatives in Choice Experiments (Meyerhoff & Liebe, 2009). Moreover, Scarpa, Ferrini, & Willis (2005) argue that including an ASC in the econometric analysis captures unobservable influences beyond attributes present in the choice sets. A significant ASC, representing the SQ alternative or the designed choice alternatives, then might suggest that an *Status Quo* effect occurs (Boxall, Adamowicz,& Moon, A., 2009; Adamowicz et al., 1998). Additionally, given that the farmers in the sample were growing different varieties in the past, the ASCs were interacted with the variety that they are growing (Bt and non-Bt). Thus, the attitude towards the ASC for the different growers will be captured.

In addition, by including a monetary attribute (seed cost), it is possible to estimate the Willingness To Pay (WTP) for the non-seed cost attributes. This is done by dividing the non-price attribute with the seed price attribute, as specified below:

$$\text{WTP} = -\frac{\beta x}{\beta price} \qquad (4)$$

Where β_x is the coefficient of the attribute of interest and β_{price} is the price coefficient.

Identification of Attributes and levels

As in all DCE application, the identification of the attributes and levels is a first important step. The varieties were described using five attributes (table 3.1):

i) *Required number of insecticide treatments*: the recommended number of treatments in Burkina Faso for conventional cotton is six. The first four treatments target Lepidopteran insects and the last two treatments control secondary pests such as Jassids and Aphids. The existing GM variety allows farmers to spray only twice targeting the secondary insects groups. However, a third level of four insecticide treatments was defined to see whether there are tradeoff with other characteristics. This third level is also sustained by the recent development in Bt cotton farms, where resistance of non-targeted insects was observed, so that the number of required insecticide treatment tends to increase.

ii) *Seed Price*: the existing GM variety grown in Burkina Faso costs 27.000 CFA per sack per hectare. However, the seed price has been pointed by a number of studies as the main constraint impacting the economic benefit. This negative impact on the economic benefit is perceived by cotton growers as a consequence of the surplus of the number of seed sac used per hectare due to climatic hazards faced every agricultural season. To appraise which price will be acceptable for farmers, three lower price levels 25.000; 17.500; 10.000 FCFA and one higher price of 30.000 FCA[8] were used.

iii) *Seed development*: Seed provenance has been at the core of the GMO debate, where the opponents criticize the monopolistic way to control seed production by multinationals. In the case of Burkina Faso however, the Bollgard II® seeds were developed under a partnership between the lead cotton company Sofitex (Societe Burkinabe des Fibres Textiles) and Monsanto. In our experiment three levels are included: public, public private partnership and private

[8] $1 = 592 FCFA (currency)

iv) *Change in agricultural practices*: The cultivation of GM crops might also require changes in agricultural practices. The attribute captures whether such changes are necessary or not.

v) *Yield*: to get a reliable range of yields the Sofitex database on ten years of production was consulted. This covered the last 5 years before and the first 5 year after the Bollgard II® commercial release. Finally three levels of yield were used and adjusted based on the type of farmers (Large, Medium and Small).

To sum up, a total of three attributes with three levels (3^3) were coupled to an attribute of four level (4) and two levels (2).

Table 3.1: Attribute and levels of Attributes for the Choice Experiment

Attributes		Levels of Attribute 1	2	3	4
1. Number of Spray (Treatment)		6T	4T	2T	
2. Seed Price (CFA)		30.000	25.000	17.500	10.000
3. Seed Provenance		Private	Public	Public-private partnership*	
4. Agricultural Practices		Change	No change*		
5. Yield (kg/ha)	Small (≤2ha)	675	750	900	
	Medium (<2ha-5ha≤)	900	1.000	1.200	
	Large (>5ha)	1.200	1.350	1.600	

*Represent the Status Quo level, except for "Yield" and "Number of Spray" where their current values are inserted as its Status Quo level.
"Seed price" the Status Quo level is the current price on the market of 27.000 CFA for Bt producers and 7.000 CFA for conventional producers ($1 = 592 CFA).

Design of Choice Sets

Once the attributes and their levels are identified an appropriate design should be constructed. This involves combining the attribute levels into choice profiles (or alternatives) and grouping the profiles in choice cards (Carson,1994). Thus, according to the five identified attributes and their levels (table 2), a fractional factorial design generates a sample of the full design (3^3 x 4 x 2 = 216) in such way that the most important effects are estimated (Lindsay, Hanson, & McPake, 2009). The D-efficiency approach was used to design the experiment with the help of SAS software (Kuhfeld et al., 1994). A D-efficient design tends to greatly reduce the predicted standard errors of the parameter estimate and produce even stronger statistical results (Louviere, Pihlens, & Carson, 2010; Rose et al., 2008).

Two opt-out alternatives were included (table 3.2). The first one refers to the baseline meaning a farmer could choose to continue its current way to grow cotton, while the second opt-out allow farmers to indicate a preference to stop growing cotton when compared to the other alternatives. Following Veldwijk et al. (2014), including an opt-out option in DCE leads to an unforced choice model, which may therefore induce a downward bias (Dhar & Itamar, 2003). The choice sets were compiled by means of SAS. 24 cards containing 3 alternatives were generated. In the survey, each farmer was confronted with 8 randomly chosen choice sets. This was done by splitting the 24 choice sets generated by SAS into 3 blocks of 8 choice sets. Blocking helps to promote response efficiency by reducing cognitive effort for each respondent (Johnson et al., 2013). A total of 12.960 individual choices were obtained by the study (5 alternatives x 8 choice cards x 324 farmers). Table 3.2 below presents an example of one of the choice cards.

Table 3.2: Example of choice set addressed to Small farmers group

Attributes	**Alternative 1** ☐	**Alternative 2** ☐	**Alternative 3** ☐
Yield (Kg/ha)	675	900	750
Number of Sprays	4 T	2 T	6 T
Seed cost (CFA/ha)	17.500	10.000	25.000
Seed provenance	Public-Private partnership	Private	Public
Agricultural practices	Change	Change	No Change
Alternative 4: I prefer to maintain my current way to grow cotton ☐			
Alternative 5: I would like to stop growing cotton ☐			

3.4. Results and Discussion

3.4.1. Farmer characteristics

All of the farmers surveyed were male and the majority were in the age groups 31-40 (39.2%) and 41-50 (43.4%). Most farmers (over 80%) had not had any formal education. Only 2.8% of the selected farmers had received formal education in agriculture, 11.4% had followed primary education and 4.9% secondary. The overall experience of the selected farmers with cotton production was slightly greater than 25 years. Seven years after the introduction of Bollgard II® in Burkina Faso the farmers growing Bt had, on average, 6 years of experience with this crop, but even those not growing Bt at the time of the survey had on average tried it for 2 years. The average surface cultivated with cotton by the interviewed farmers was around 4,5ha. When looking at the yield performance (table 3.3), Bt growers on average had a yield of 1115,27 Kg/ha and non-Bt growers on of 953,23 Kg/ha.

Table 3.3: Basic demographic background and yield component from the farmers surveyed

Parameters	Type of Farmers Small (n = 108)	Medium (n = 108)	Large (n = 108)	Total (n=324)	
Age					
up to 20	2			2	**0,6%**
21 - 30	9	11	2	22	**6,8%**
31 - 40	37	55	35	127	**39,4%**
41 - 50	52	27	62	141	**43,4%**
51 - 60	7	13	7	27	**8,4%**
over 60	1	2	2	5	**1,6%**
Education level					
Non	29	35	39	103	**31,8%**
Non formal	56	51	52	159	**49,1%**
Primary	13	11	13	37	**11,4%**
Secondary	7	7	2	16	**4,9%**
Formal agricultural background	3	4	2	9	**2,8%**
Yield Component (2015-2016 campaign)					
Average surface (ha)	1,7	3,5	7,9		**4,4**
Yield (Kg/ha) for Bt growers (n=162)	989,72	1121,64	1234,64		**1115,27**
Yield (Kg/ha) for Non-Bt growers(n=162)	870,7	960,74	1028,24		**953,23**
Yield improvement (Bt vs Non-Bt)	12%	14,3%	16,7%		**14,5%**

3.4.2. Conditional Logit

The CL model was estimated using NLOGIT 5 software. Two CL model were performed both considering general farmers preference of the entire sample as well as the preferences according to farm size parameter. The estimation results of the Conditional Logit Model for the whole sample (table 3.4) showed that all of the attributes are significant determinants of farmers' preferences. Farmers have a preference for higher yields and a lower number of required insecticide treatments. The preference towards the number of spray supports previous studies pointing that the insect resistance is one of the main reasons spurring the adoption of Bt cotton in Burkina Faso (Vognan et al., 2002; Traoré et al., 1998). Cotton growers also prefer seeds to be developed under a pure public or a public-private partnership above a pure private initiative and affordable prices. Increases of the current seed price would be negatively perceived by farmers. The current collaborative partnership was found suitable by farmers. A similar adhesion of farmers to this parastatal seed development system was previously mentioned in a study conducted on the assessment of the impact of institution on Bt cotton implementation (Méda et al., 2018; Dowd-Uribe, 2014). Overall, farmers of this study expressed a positive preference to change their current way to grow cotton by referring to the agricultural practices attribute.

The rate of choosing the status quo variety was also valued comparing to the others alternatives varieties. Table 3.4 also provides information about the choices made by farmers whether staying with the Status Quo variety or going for the alternatives varieties. None of the farmers indicated a preference to stop growing Cotton. This finding is in accordance with the recent study of Sanou et al. (2018) about farmers opinions on the decision to abandon Bt cotton variety in Burkina Faso that found that the majority of cotton growers (Bt and non-Bt) were against the decision to suspend cultivation of Bt cotton. Our model showed that both the Bt and non-Bt growers had an opposite preference towards their current situation. Thus, it is interesting to mention that when considering the entire sample about 51% of the participants prefer to keep their current variety. However, the segmentation results based on the type of variety grown revealed that nearly 59% of Bt farmers prefer the Status Quo versus a slightly more than 43% of the conventional growers. While majority of Bt growers had a tendency to choose the Status Quo variety, a negative attitude towards the current variety was observed from non-Bt farmers preferences. This confirms earlier studies (Fok, 2016; Vitale and Greenplate, 2014; Vitale et al., 2010, 2011) that found that farmers are quite satisfied with the characteristics of the current Bollgard II® variety. Accordingly with the choice of Status Quo variety made by non-Bt growers, our data suggest that approximatively 60% of them expressed a willingness to adopt an alternative GM variety with higher yield, low number of insecticides treatments at an affordable price.

Table 3.4: Utility Derived from all sample

Utility parameter	Coefficient	Standard Error
Yield	.00418***	.00013
Private seed source[1]	-1.10502***	.06893
Public seed source[1]	.77039***	.04905
Number of Spray	-.59463***	.02548
Seed Price	-.08727***	.00492
Agricultural practices	.13576***	.03719
$ASC_{SQ\ x\ Bt\ grower}$	.42554***	.06119
$ASC_{SQ\ x\ NonBt\ grower}$	-.08359*	.04531
Probability of selection an opt out alternative		
Alt4: Preference for the status quo		51% (58.6% Bt, 43.2 Non-Bt)
Alt5: Abandon of cotton growing		0%

[1]Compared to public-private partnership; ASC_{SQ}: Alternative Specific Constant for the Status quo; ***, **, * = Significant level at 1%, 5%, 10% level

When looking at the results of the conditional logit for different farm sizes (table 3.5), it's interesting to consider that a slightly more than half of "small" and "large" farmers groups prefer the Status Quo. The negative attitude towards the ASC for small and medium non-Bt growers, suggest that this farmers might not be satisfied with this crops for reasons beyond the described attributes. However, results also highlighted that farmers owning less than 2 ha are neither satisfied with the Bollgard II® variety. This level of appreciation from small-scale farmers could be related to the findings of Renaudin et al. (2012), where the financial risk of Bt cotton towards small farmers was questioned owing to the current Bt seed price. More recently, Sanou et al. (2018) also found that the seed price policy was the main constraints addressed by small scale farmers.

When considering the large farmers groups' attitudes towards the ASC, our model seems to suggest that they were satisfied with their current situation whether growing Bt or non-Bt variety. However, the assessment of large farmers preferences in this model revealed that about 51.4% adhered to the status quo variety.

Table 3.5: CLM estimation based on the type of farmers

Utility parameter	Small	Medium	Large
Yield	.00721*** (.00036)	.00537*** (.00027)	.00499*** (.00024)
Private seed source[1]	-1.30542*** (.13210)	-1.36135*** (.12297)	-1.59307*** (.13728)
Public seed source[1]	.81443*** (.09442)	.80564*** (.08351)	.91111*** (.09185)
Number of Spray	-.76542*** (.05320)	-.72264*** (.04782)	-.91640*** (.05623)
Seed Price	-.10467*** (.00947)	-.10353*** (.00864)	-.12168*** (.00970)
Agricultural practices	-.13919** (.07015)	.27694*** (.06355)	.27705*** (.06874)
$ASC_{SQ\ x\ Bt\ grower}$	-.53640*** (.13005)	.09291 (.10713)	.82464*** (.10766)
$ASC_{SQ\ x\ NonBt\ grower}$	-.79085***(.09439)	-.23509***(.07887)	.37331***(.08366)
Probability of selection an opt out alternative			
Alt4: Preference for the status quo	54,9% (Small), 46.4% (Medium), 51.4% (Large)		
Alt5: Abandon of cotton growing	0% for all		

[1]Compared to public-private partnership; ASC_{SQ}: Alternative Specific Constant for the Status quo;
***, **, * = Significant level at 1%, 5%, 10% level, (...) = Standard Error

The Willingness To Pay (WTP) for the non-seed cost attributes changes was estimated and reported in the table 3.6. Towards the change for an extra yield, our data suggest that farmers are willing to pay an average of 48 FCFA to increase their cotton yield with one unit kilogram. But when comparing the WTPs of each farmer group, it is interesting to see "Small" farmers group presented the highest WTP (69 FCFA/Kg), followed by Medium (60 FCFA/Kg) and Large (41 FCFA/Kg) farmers groups. A reason for this might be the low yield performance faced by small-scale farmers.

The change from private to public-private partnership seed development presented the highest WTP value (an average of 12.662 FCFA) when compared to others attributes. There was no significant difference among farmers groups. This confirms that farmers are willing to pay more to stay in the public-private partnership than moving for a pure private seed source. Similarly, the WTPs for eliminating one insecticide treatment were not significantly different among the farmers groups. This also sustains the aforesaid findings indicating that farmers have a preference for a cotton variety that requires low number of spraying.

Regarding farmers' preparedness to change their current agricultural practices, it is noteworthy to see that only small farmers groups showed to be reluctant to change their current practice. A reason of that might be that they are more concerned by improving their current yield than taking a risk to go for a change which can increase the production cost. Both the Large and Medium farmers groups presented a non-significant WTP value.

Table 3.6: WTP for Attribute level changes

	Willingness To Pay			
	Farmers	**Farm size**		
Attributes	**All**	**Small**	**Medium**	**Large**
Extra Yield (FCFA/Kg)	48	69	52	41
From PP partnership to				
Private seed source[1] (FCFA)	-12.662	-12.472	-13.149	-13.092
Public seed source[1] (FCFA)	8.828	7.781	7.782	7.488
Extra insecticides treatment				
(FCFA/Treatment)	-6.814	-7.313	-6.980	-7.531
Preparedness to change their				
Agricultural practices	1.556	-1.330	2.675	2.277

PP: Public-Private

3.5. Conclusion

While the introduction of Bt cotton in Burkina Faso was generally regarded as a huge success (Pertry et al., 2016; Vitale and Greenplate, 2014; Vitale et al., 2011), this perception has been mainly based on the fast uptake and on evaluations of the average productivity gains. Farmers' opinions were seldom heard in this. Critical voices furthermore also point to the top down development and introduction of the crop and to the high level of vertical integration in the cotton supply chain, where famers have to grow the seeds they receive from the cotton companies. In this light it is interesting to look whether the available variety matches with the preferences of farmers. This study therefore analyzed preferences by farmers for cotton attributes of improved GM varieties in western Burkina Faso.

Outputs of this study confirm that all of the identified attributes appeared to be significant determinants of the preferences of farmers. It has been shown that farmers have a positive preference towards yield improvements and a negative preference towards pure private variety development and towards an increase in the required number of insecticide applications as well as towards an increase in the seed costs. Overall, the development of new seed varieties whether from pure Public or Public-Private Partnership was positively perceived by farmers. Towards their preparedness to change the current way to grow cotton, the majority of farmers involved in this study are willing to change. Likewise, the earlier study of Ezezika et al. (2012) identified the change in the traditional agricultural practices as an important influencing factor to consider in order to guarantee the success of the implementation of biotechnology crops in SSA.

When looking at the proportion of preferences for the “Status Quo” option, the study found that nearly 59% of Bt growers were satisfied with their current situation. About 60% of farmers belonging to conventional growers are willing to adopt new GM varieties (with higher yield with at least two insecticides treatments, at affordable price) comparing to their current variety. Regarding the farm size, Small and large farmers groups obtained the highest score by choosing their current situation. However, only Large farmers groups presented a positive attitude towards the ASC whether Bt and non-Bt growers.

Towards the WTP for the non-seed costs attributes changes, the highest value was scored with the attribute related to stay with public-private partnership seed sources. The WTP for eliminating an insecticide treatment was not significantly different among farmers groups. As to farmers preparedness to change their current agricultural practices, Small farmers seem to be unwilling for that.

To sum up, this study found out farmer’s preferences are mainly shaped by the economic benefits due to higher yields and the reduction of number of spray and the seed cost. The current public/private partnership was found to be the most attractive from a farmer’s point of view. Nonetheless, public source of seed development could be alternatively accepted by farmers whereas a pure private initiative was badly perceived.

PART THREE: Biofortified Sorghum Event

Chapter 4: Farmers' Valuation of Transgenic Biofortified Sorghum for Nutritional Improvement in Burkina Faso: A Latent Class Approach[9]

Abstract

Micronutrient malnutrition has been a challenge in Burkina Faso for many years and has led to a worsening food security situation. Vitamin A, iron and zinc deficiencies affect 1 in 4 persons in the country and are responsible for early child nutritional disorder. The high prevalence of micronutrient malnutrition may be attributed to the dominant role in the diet of local sorghum varieties, deficient in essential micronutrients. To address this issue Africa Harvest is developing a biofortified sorghum variety. However the success of this innovation among farmers will depend on numerous factors such as product attributes, previous experience and socioeconomic factors. In this study, we applied a choice experiment to investigate the farmers' valuation of various sorghum seed attributes as well as to identify the factors that influence the farmers' valuation. Our results show that there is a market for transgenic biofortified food in the country and thus that it could be a veritable instrument for reducing micronutrient malnutrition problems. We found that farmers are willing to pay more for biofortified sorghum, particularly if it also scores better on other attributes than the local varieties. .Furthermore, we showed that those that have experience with the first-generation genetic modified crop (Bt cotton), are more likely to adopt the second-generation crop (biofortified sorghum). Given the importance of the other attributes and the heterogeneous preferences it is key to involve farmers in the development of the new product.

Keywords: Farmers, Transgenic biofortified Sorghum, Micronutrient malnutrition, Choice experiment, Latent Class Model

[9] This chapter was based on: Chinedu Obi , Edouard I.R. Sanou, Juan Tur-Cardona, Fabio Bartolini , Godelieve Gheysen, Stijn Speelman (2018). *Farmers' valuation of transgenic biofortified sorghum for nutritional improvement in Burkina Faso: A latent class approach*. June 2018, *Food Policy*. DOI: https://doi.org/10.1016/j.foodpol.2018.06.006

4.1 Introduction

Micronutrient malnutrition (MNM) is an important contributor to the global burden of diseases (International Food Policy Research Institute, IFPRI, 2016). It has been a challenge in Burkina Faso for many years, where it has led to worsening food security situation (World Food Programme, 2017). MNM in form of vitamin, iron and zinc deficiencies affects 1 in 4 persons in the country (FAO, 2014). A UNICEF report showed that while 34% of the country's population are chronically malnourished, above 10% suffers from acute malnutrition (UNICEF, 2013). Furthermore, another report showed that Burkina Faso has a very high level of infant mortality rate, averaging at 129 per 1000 live-birth, with 34.6% of children being stunted and 25.7% underweight (IFPRI, 2015).

The high prevalence of MNM in Burkina Faso may be attributed to its location in an arid region where the climatic and soil conditions are unfavorable for sustainable cultivation of highly nutritious food (Li et al., 2012; Miller and Welch, 2013; Obi et al., 2017). For instance, it was found that the local sorghum cultivar, the most important staple crop, is deficient in essential micronutrients (da Silva et al., 2011; Paiva et al., 2017; Traore and Stroosnijder, 2005). Therefore, by continuously consuming this starchy crop, the nutritional needs of the rural poor are not met.

The initiative to improve the nutritive content of the local sorghum cultivar through biotechnology was taken by Africa Harvest International (AHI) in 2001. The project was funded under the Grand Challenges in Global Health initiative by the Bill and Melinda Gates Foundation. The resulting African Biofortified Sorghum (ABS) would contain increased levels of vitamin A, Iron, and Zinc (AHBFI, 2007).

Nevertheless, for a new biofortified crop to achieve success in reducing the problem of MNM in the country, it must be highly valued by the rural poor. This can only be possible, however, if the dissuading factors are eliminated. First, transgenic biofortification as the second generation of genetic modification (GM) projects is still in its early stage of development (De Steur et al., 2017), yet it is mired with strong controversies. These controversies may play an important role in the adoption decision of farmers (Adenle et al., 2013). Second, biofortification can alter the sensory attributes of crops such as taste, fragrance and colour (De Groote et al., 2014). These changes have been found to deter the acceptance of non-transgenic biofortified crops in many developing countries (Banerji et al., 2016).

In Burkina Faso, aside from the GM controversies and the possible changes in product attributes, the local food culture is another factor that can play a role in the farmers' adoption. In earlier attempts to introduce improved sorghum varieties with better agronomic attributes, studies have shown that the farmers kept preferring their local sorghum cultivar (Adesina and Baidu-Forson, 1995; Olembo, et al., 2010). Issues relating to perceived superiority of the attributes of local cultivars, penchant to seed saving culture, and transaction costs were identified. Although a noticeable adoption level was later reported, thanks to the introduction of the participatory sorghum breeding project. Nonetheless, the recorded improvement is only pronounced in the project areas whereas adoption of improved varieties at the national level is still as low as 3 to 5% (CIRAD, 2016).

The new transgenic biofortified variety is being produced to provide an additional nutritive attribute that is not available in either the improved variety nor the local varieties. Following Saltzman et al. (2013), we hypothesize that farmers will not only consider the nutritive value of the biofortified variety, but also the agronomic and economic attributes when making adoption decision. Therefore, the objective of this research is to determine the market potential of the transgenic biofortified sorghum in the country. To achieve this, we estimated the farmers' valuation, or rather the welfare drawn from hypothetical attributes of the biofortified variety. Furthermore, we examined how their socioeconomic characteristics, experiences, local practices, and motivations influence their valuation of the new variety, and calculated the farmers willingness to pay for attribute changes.

The study contributes to the existing literature in market potential of transgenic biofortified crop in twofold. First, the Discrete Choice Experiment (DCE) methodology used in the study is quite unique. Most ex ante studies conducted on farmers' choice for transgenic crops use contingent valuation presenting a dichotomous choice between a transgenic variety and a non-transgenic variety (Hubbell et al, 2002; Krishna and Qaim, 2007; Qaim and de Janvry, 2003). This method has been subjected to criticisms in terms of its ability to deliver reliable and accurate estimates (Mogas et al., 2006). For instance, Hanley et al., (2001) observed that the approach is not suitable to deal with cases where attributes valuations are multidimensional. Furthermore, compared to other related DCE studies which used multinomial logit model (Birol et al, 2007; Breustedt et al., 2008; Schreiner, 2014), our study is different because it accounts for farmers' preference heterogeneity.

Different models of DCE that can account for unobserved heterogeneity as well as potential source of variabilities in decision makers' preference have been contrasted by Greene and Hensher, (2003). Considering the three possible alternatives (parametric mixed logit model, random parameter latent class model, and the semi-parametric latent class model), Kikulwe et al. (2011) posited that when the objective is to segment a population based on the welfare derived from a new technology, a semi-parametric latent class model (LCM) is most relevant from a policy perspective. Therefore, by using this LCM, we were able integrate a wide spectrum of product alternatives and covariate parameters that segmented our respondents based on homogeneous characteristics within, and heterogeneous across. Segmentation is a very useful marketing strategy to identify different categories of farmers and how they value a product.

Secondly, the addition of the seed source attribute to the DCE is innovative. Arguments have been put forward on how the source of transgenic seeds and their distribution conditions influence farmers' adoption. For example, while Mabaya, et al. (2015) stated that the potential of transgenic crops to improve nutritional security in Sub-Saharan Africa (SSA) depends to a large extent on the farmers' access to the seed, Andekelile and Leon, (2016) added that the conditions on which seeds are distributed are vital, and should harmonize with farmers' experience and practices. Seed saving practice might lead to low adoption of new transgenic crop varieties, specifically if new seeds are protected by intellectual property rights and seed reuse restriction conditions applies (Black et al., 2010). Furthermore, when the rural poor farmers are obliged to purchase the transgenic seeds every planting season, the traditional seed exchange behaviors may be disturbed, thereby greatly affecting the market of transgenic seeds (Azadi et al., 2015; Garcia-Yi et al., 2014). While these arguments have always resurfaced in many GM debates, the degree to which the seed source and distribution conditions influences farmer's preference for transgenic biofortified seeds was never captured in a DCE.

The rest of the paper is structured as follow: in the second session, the Choice experiment method is presented, starting with the theoretical framework. This is followed by the description of the choice experiment design and data sampling method. The results and discussions come afterwards in session 3, then the conclusion and recommendations follow in the last session.

4.2 Choice Experiment Method

4.2.1. Theoretical Framework

Choice models are based on the theory of individual choice behavior which captures the farmers' preference for attributes that make up a product (Louviere et al., 2008). It has its theoretical origin in Lancaster’s’ model of consumer choice (Lancaster, 1966), and the theory of Random Utility. Lancaster stated that satisfaction will be obtained from the attributes of a product rather from the product itself, while Random utility observed people to be rational and as such, when presented with two or more options, they would likely decide in favour of the one providing them with higher utility. To elicit the preference of an individual from a set of alternatives, a DCE is often applied. As a stated preference elicitation method, DCE is appropriate when a product is new and/or not yet commercially available (Louviere et al., 2000; Lindsay et al., 2009). Unlike the revealed preference method, stated preference methods give the researcher the room to include hypothetical attributes which might not be available in alternative products that are already in the market.

The LCM is one of the econometric models that can be used to analyse DCE data The LCM simultaneously identifies subgroups having homogenous preferences for an attribute and the characteristics which these groups have in common. It assumes that individuals reside in ‘latent' classes which are unknown to the analyst, with each class having a homogenous preference structure. Classes, otherwise referred as segments in this article, are often determined by the socio-economic characteristics of the respondents and choice of product attribute. In related literature on transgenic crop market research, a LCM was applied by Birol et al. (2011), Kikulwe et al. (2011) and Birol et al. (2007). In the latter two studies, motivational questions concerning farmers' knowledge, perception and attitude towards the transgenic food were included to segment membership structure. It was observed in all the studies that a significant heterogeneity exists in respondents’ preference for transgenic foods. The result is particularly important in market segregation and targeting. For instance, in Uganda, Kikulwe et al. (2011) observed that the biofortified banana should be a pro-poor program targeting rural farmers. Therefore, by applying LCM in our study, we can provide relevant information to policy makers and product developers for product development and marketing strategy.

Following the econometric model specification proposed by Greene and Hensher (2003), before the LCM, a Conditional Logit (CL) may first be specified. While the CL presents a holistic preference of all respondents, the LCM gives a segmented preference structure. The general econometric model consists of parameterized utility functions $U_{nij/s}$ in terms of observable independent variables $\beta_s X_{nij}$ and unknown parameters or Error components $\varepsilon_{nij/s}$ as shown below.

$$U_{nij/s} = \beta_s X_{nij} + \varepsilon_{nij/s} \qquad (1)$$

Simply put, $U_{nij/s}$ is the utility that a farmer *n*, who belongs to a segment *s* derives from the selection of alternative *i* in the choice set *j*. The *β* is the segment-specific parameter vector which encompasses first, the choice parameter, and second the socio-economic and motivational parameter vectors. While *X* is the vector of attributes, *ε* is the error component. The inclusion of the error component implies that researchers can only predict with some level of uncertainty the choice of the respondent; therefore, it is assumed that choices made among the alternatives will be a function of the probability that the satisfaction associated with the selected option is higher than that of the alternatives not selected. Nevertheless, for this probability function to be accurate, the error term must be identical, independently distributed and follow a Type 1 or Gumbel distribution (Rungie et al., 2011). If this is the case, the conditional probability that the farmer *n*, belonging to segment *s*, selects the alternative *i* in the choice set *j* is given as

$$P_{nit/s} = \frac{\exp(\beta_s X_{nij})}{\sum_{i=1}^{I} \exp(\beta_s X_{nij})} \qquad (2)$$

And the probability that the farmer belongs to the segment is expressed as:

$$P_{ns} = \frac{\exp(\alpha_s \theta_n)}{\sum_{s=1}^{S} \exp(\alpha_s \theta_n)} \qquad (3)$$

Where α_s is the segment-specific parameter vector to be estimated (i.e. the characteristics of the farmer that contributes to the membership of a segment) and θ_n is the individual specific variable (attributes of the product). Therefore, the probability that the farmer chooses an alternative is the conditional joint probability from equation (2) and (3), as specified below as

$$P_{ni} = \sum_{s=1}^{S} \left(\frac{\exp(\alpha_s \theta_n)}{\sum_{s=1}^{S} \exp(\alpha_s \theta_n)} \right) \prod_{j=1}^{J} \left(\frac{\exp(\beta_s X_{nij})}{\sum_{i=1}^{I} \exp(\beta_s X_{nij})} \right) \qquad (4)$$

By including the seed cost attribute, it is possible to calculate the farmers' valuation or willingness to pay (WTP) for product attribute changes. This is done by dividing the non-price attribute with the seed price attribute, as specified below

$$\text{WTP} = \frac{\beta_k}{(-)\beta_c} \qquad (5)$$

Where: β_k is the coefficient of a non-seed price attribute, and β_c is the coefficient of the seed price attribute. In determining the farmers' valuation or welfare measure, attributes presented in quantitative form are compared with another quantitative attribute. A similar process is used for qualitative attributes. By so doing, the valuation that farmers attach to the attributes can be compared between the segments identified in the LCM.

4.2.2. The Choice Experiment Design

The different stages in the design of the choice experiment are well-elaborated by various researchers (Hanley et al., 2001; Hoyos, 2010; Lindsay et al., 2009). The first stage of DCE is to select the relevant attributes of the product. Relevant attributes for transgenic biofortified sorghum were identified by combining literature review with experts' opinion. Literature includes previous studies on the adoption of high yielding traditional bred sorghum in Burkina Faso, as well as studies on farmers' perception and adoption decision of transgenic crops in Sub-Saharan Africa (SSA) (Adesina and Baidu-Forson, 1995; Kuwornu et al., 2011; Lacy et al., 2006; Olembo et al., 2010; vom Brocke et al., 2010; Zakaria et al., 2014). The engaged experts include researchers from the AHI consortium, the *Institut National de l'Environnement et de la Recherche Agricole* (INERA) and the Ministry of Agriculture and Food Security in Burkina Faso. The experts were selected based on their knowledge of the ABS project and farming system in Burkina Faso.

During the expert consultation, five attributes were selected reflecting important sorghum characteristics. These include micronutrient, seed price, seed source, yield and maturity date. The use of a limited set of attributes is a fair standard assumption in DCE model as it helps to improve the respondents cognitive ability to complete the experiment (Lindsay et al., 2009). Often, focus groups are organized to define an appropriate set of attributes (Alpizar et al., 2001), but because of the security situation in the country at the time of the design, it was opted to go for individual expert consultations. Finally, pretesting of the CE with some farmers confirmed that the attributes included were relevant.

The second stage is assigning attribute levels. There is no agreed optimal number of level, but the levels assigned must reflect the range of situations that the respondents might expect to experience, and they should be feasible and realistic (Lindsay et al., 2009 and Hanley et al., 2001). Literature review, expert consultation, and market surveys were used in the selection. Where quantitative values were used for example in seed price, yield and maturity attributes, the status quo represents the current (or estimated) average value of such attribute. Additional levels were added to this base level as shown in Table 4.1, and further explained below.

Table 4.1: Attributes and levels of attribute for Choice experiment

Attributes	Definitions	Levels
Increased Micronutrients	Whether or not an additional micronutrient is present	Yes, No*
Seed price (CFA)	The amount paid for the purchase of seed per Kg	5000, 4000*, 3000
Seed source	The sector responsible for the production and marketing of seed	Private, public*, public-private partnership
Yield (Kg)	The expected yield per hectare (Kg)	650, 750*, 850, 1000
Days to Maturity (days)	Number of days taken for the crop to mature	70, 80*, 95, 110

*Represent the baseline level, $1 =592 CFA

The first attribute "increased micronutrients" refers to the extra micronutrients that could be added to the existing varieties. This attribute is the most important feature of the biofortified sorghum programme, and the major difference from the normal improved varieties. Two levels were suggested: Yes, indicating the presence or No indicating the absence of extra micronutrients. As the transgenic biofortified sorghum has not yet been commercialized, the exact type and level of nutrients to be added is undefined, thereby making qualitative levels the preferred option. More so, although Vitamin A is the target nutrient, the AHI experts that were consulted hinted that other micronutrients are also considered.

The "seed price" attribute is the price of sorghum seed per kg. It is a monetary variable that is relevant in the estimation of the utility derived from the other attributes of the product. Three levels were proposed. The first level 4000 CFA is the current average price of one Kg of the improved sorghum variety in the country. The other levels 5000 CFA and 3000 CFA are relevant estimates proposed by the consulted experts from the Ministry of Agriculture and Food Security. The rational for adding a higher and lower price level is that the AHI may decide to sell the ABS seed for a higher price than the improved variety because of its extra nutrient. A lower price may equally be decided as a market penetration strategy since the farmers are not used to buying seeds in the market.

The “Seed source” attribute describes the sector that manufactures and provides the seed to the farmers. This attribute is added from the backdrop of the argument that farmers in SSA might be less willing to adopt transgenic crop seeds whose seed provider and conditions are alien to local experience (Andekelile and Leon, 2016; Mabaya et al., 2015; Virgin et al., 2007). Three “seed source” levels (public, public-private partnership and private) were considered in the choice experiment. The public seed sector represents the baseline level, because most improved varieties are developed and marketed by this sector (Azadi et al., 2015). In Burkina Faso, new varieties of sorghum seeds (produced by INERA and other regional public research institutions) are often distributed publicly by the state run seed distribution agency, the certified seed producers, and the local farmers’ organization (CIRAD, 2016). The second level, public-private partnership is a development and distribution approach that is jointly organized by public institutions and private seed manufacturing companies. An example of such partnership in Burkina Faso can be observed in the Cotton sector (Sanou et al., 2018). The third level is private. Current involvement of the private sector in development and distribution of sorghum seeds is very low, and the fact sorghum is a subsistence crop and that most of the farmers are poor smallholders makes greater private sector engagement difficult (Smale et al., 2018). Nevertheless private seed companies are active for other field crops and vegetables in Burkina Faso (Diallo, 2018).

The “Yield” attribute is the anticipated yield of the product per hectare. The baseline yield 750kg/ha was obtained through the consultation with experts in the Ministry of Agriculture and Food security. The study of Lacy et al. (2006) on farmer choice of sorghum varieties in southern Mali gave an insight on the other levels. The yield attribute is important to evaluate the findings of previous research by Adesina and Baidu-Forson (1995) who opined that the yield attribute of sorghum is “barely significant” in farmers adoption of modern sorghum varieties.

The final attribute “Days to Maturity” refers to the number of days taken for the crop to mature. In an arid country, a crop with a shorter maturity period means a higher ability to resist the climatic variations, and it is often preferred. Again, the study of Lacy et al. (2006) was vital in the identification of levels. Four levels were specified with 80 days being the average of sorghum maturity date in the study area.

The third stage in the DCE is designing the choice set. A choice set is a group of hypothetical alternatives constructed through experimental design. Among available alternatives, a fractional factorial design was used for the study. The fractional factorial design generates a sample of the full design in such that the most important effects can be estimated (Lindsay et al., 2009 and Alpizar et al., 2001). One advantage of fractional factorial design is that the reduction in the number of choice sets does not lead to a concomitant loss in estimation power (Hanley et al., 2001). The D – efficiency approach of fractional factorial was used to design the experiment with the help of SAS software (Kuhfeld et al., 1994). A D-efficient design tends to greatly reduce the predicted standard errors of the parameter estimate and produce even stronger statistical results (Hoyos, 2010; Rose et al., 2008). The alternatives were not labelled, because it could make the respondents ignore the attributes and concentrate on the labels (Saldias et al., 2016). This is particularly a problem in sensitive market research like transgenic food, where a strong attitude exists due to controversies and external influences.

In the choice set, two opt-out alternatives were included. One describing the desire to continue with current sorghum seed, and the other, the intention to abandon sorghum production if a transgenic variety is introduced. The addition of these opt-out alternatives is used to determine the farmers' penchant to the local sorghum cultivar and their attitude towards transgenic crops. The respondents were also asked during the interview about their current yield and their frequency of seed purchase, in a way that their current values for the status quo could be used in the analysis. To avoid that the survey would become too long, the design was blocked into 2 partitions. Blocking helps to promote response efficiency by reducing cognitive effort for each respondent (Johnson et al., 2013). Respondents were randomly assigned to one of the blocks, facing 6 choice sets or situations. A total of 5400 individual choices were obtained for the study (6 alternatives x 6 choice sets x 150 farmers). Figure 4.1 presents an example of one of the choice sets.

Figure 4.1: Example of choice Set

If an GM Sorghum variety would be introduced , which alternative would you prefer?

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Micronutrient	Yes	No	No	Yes	I prefer the local sorghum seed	I will totally abandon sorghum production
Seed cost	3000	5000	4000	4000		
Seed Provider	PP	Public	PP	Private		
Yield	650	850	1000	750		
Maturity date	110	80	70	95		
	☐	☐	☐	☐	☐	☐

4.2.3. Sampling and Data Collection

The respondents for the research were a subsample of the sample of cotton farmers collected for the project *SOCBIOAfri- Addressing Societal Challenges of Biotechnology in Africa,* *Towards Balanced Innovation.* This larger dataset contained 324 cotton producing households spread across cotton producer's groups, *Groupement de Producteurs de Coton*, (GPC) in 3 districts of Burkina Faso (Dedougou, Bobo, and Diebougou). Sanou et al., (2018) fully described the sampling method. In summary, the data was collected in the 2015-2016 agricultural season and in the cotton producing area of Western Burkina Faso.

Since it is the tradition in Burkina Faso that most cotton farmers also cultivate sorghum and maize (Sanders, 2016), our sample-frame is a sub-set of the cotton farmers who produce sorghum. The process of selecting these farmers followed a stratified random sampling procedure. We first selected GPCs with at least two sorghum producing member, this is followed by random selection of 2 or 3 sorghum farmers per GPC. Ensuring that a balanced number of respondents were selected per district, and in consideration of the budget constraints, we selected and interviewed only 150 farming households (50 per district) for this research. Farmer' characteristics of this subsample are similar to those of the larger sample of 324 farmers. By being members of cotton producers organization, our respondents are believed to be reasonably informed, have good networks, and possibly among the first groups to adopt the biofortified seeds if released (Zongo et al., 2015).

Although we acknowledge that our sample size is small and may prevent the detection of small effects, it is sufficient to deliver a reliable estimate (de Bekker-Grob, et al., 2015). More so, we adopted some techniques to improve the statistical power of our sample size. First, we adopted the D-efficient (optimal) design procedure which is effective in producing a reliable estimate when sample size is small (Hoyos, 2010; Johnson et al., 2013; Rose and Bliemer, 2013). Second, we used unlabelled alternatives as labelling would require a larger sample (Hensher et al., 2005). Thirdly, our sample size is within the range adopted by 41% of DCE studies reviewed by de Bekker-Grob et al., (2015). Finally, it is by far higher than the minimum sample sizes recommended by some researchers. For instance, the 50 by Rose and Bliemer (2013) and the 20 respondents per version in a block experiment by Lancsar and Louviere (2008).

Data was collected from the household head using a structured questionnaire by a trained survey team. The survey was conducted face to face. The individual assessment was adopted due to the sensitivity of the subject matter. In each interview session, the respondents received information on transgenic biofortification and were notified of the ABS project. This was followed with a short description of the experimental setting, clear definitions of the product attributes, how to respond to questions, and assurance of the confidentiality of their response.

The survey usually took 30 minutes per session, covering 3 parts. 1. information regarding their socio-economic and farm characteristics, 2. A set of motivational questions to ascertain their nutritional knowledge and attitude towards GM crops, and 3. the application of the choice experiment.

4.2.4. Data Analysis

The socio-economic and farm characteristics were evaluated using descriptive statistics like mean and Analysis of Variance (ANOVA). The 17 motivational questions were structured into 5 points Likert scale which ranged from Strongly disagree (1) to Strongly agree (5). To group farmers based on their response to the motivational questions, a principal component analysis (PCA) was conducted. The PCA was used to remove correlation, reduce complexities, and synthetize more relevant factors (or classify variables). The criteria for accepting factor solutions (number of components) were set on a minimum eigenvalue of 1 and factor loadings above 0.30. However, other conditions such as the information on the screeplot, number of variables loaded in each factor, and the theoretical sense of the loadings were also considered. The factor score was used to assign individuals to different components. A positive coefficient indicates a likelihood of possessing the feature explained by the associated component. The coefficient of the factors was obtained using the factor score command in the STATA 13 software.

Finally, the factors obtained from PCA and the explanatory variables included in the socio-economic characteristics were used as class membership parameters in the LCM of the choice experiment.

4.3 Results and Discussions

4.3.1. Socioeconomic and Farm Characteristics

Table 4.2 presents the socioeconomic characteristics of the respondents. From the 150 farm household heads interviewed, 140 (93.3%) were males, and the average age was 44.6 years. The level of education was low, with only 32% having any form of formal education. The mean farm size per household was 8.25 ha from which on average 1.57 ha (19%) was allocated to sorghum production. The average sorghum produced by the respondents was 790 kg/ha per season. Sorghum was the most important food staple reported by 72.7% of the respondents, and most of them (84.7%) cultivate it every season. Sorghum is cultivated mainly for household consumption (91.3%). Most farmers (92.7%) still practice seed saving, but about 60% indicated that the source of their seed did not matter to them. Although, the seed saving practice is a constraint to adoption of new sorghum varieties also reported in previous studies (Adesina & Baidu-Forson, 1995; CIRAD, 2016; Olembo et al., 2010), our study show evidence that this practice can be broken since 60% of the respondents may not be influenced by the source of the seed.

The means of the socioeconomic and farm characteristics of the respondents in the 3 districts were compared using ANOVA. The result shows that there were no significant differences in any of the variables across the three districts.

Table 4.2: Socio-economic and Farm Characteristics of farmers

Parameters	Total Sample(150)	Bobo (N=50)	Dedougou (N=50)	Diebougou (N= 50)
Socioeconomic characteristics				
Gender (% of males)	93.3	94	92	94
Age (average years)	44.6	45.20	44.26	44.44
Education level (% literacy)	32	36	38	42
Sorghum acreage (hectare)	1.59	1.60	1.41	1.77
Total acreage (hectare)	8.25	9.88	8.81	6.07
Total annual yield (Kg/ha)	790	801	761	807
Farm Characteristics (% of yes)				
Importance of sorghum				
Sorghum as household staple	72.7	74	68	76
Grows sorghum every season	84.7	92	82	80
Purpose of sorghum production				
Consumption only	91.3	94	92	88
Sales only	8.7	6	8	12
Sorghum seed provision				
Save seed for next season	92.7	94	92	92
Sometimes purchase seed from market	6.7	6	10	4
Seed source does not matter	59.3	68	60	50

4.3.2. Motivational Factors

Three components were obtained from the PCA which satisfied the criteria set for selection (Table 4.3). The first component (factor 1) gathers five statements which could be related to “the awareness of the biofortified sorghum”. The second component (factor 2) was labelled “risk-aversion ” referring to the four statements composing this factor. The last component (factor 3) was associated to “Negative experience”.

From this PCA outcomes, the factor scores were used to categorize the farmers. We found that about 63.3% of the farmers had a high score for the second component. These non-risk takers demand more information, affordable price and government approval before they would adopt the new product. About 56% had a high score for factor 1. These respondents showed great understanding of the micronutrient deficiency in the local sorghum cultivars and were aware of the transgenic crops. Finally 36% have high scores on negative experience . The respondents of this group are regularly informed of research on improved sorghum varieties but due to previous bad experience with hybrid varieties introduced to them, are most likely to continue with their local cultivars.

Table 4.3: Principal Component Analysis Result (N = 150)

	Motivational Statements	Rotated Factor Loading (Varimax)		
		Factor 1	Factor 2	Factor 3
1	Do you know that the public health studies in Burkina revealed deficiencies in vitamin A, iron and zinc for children under 5 and women?	**0.36**	0.18	-0.06
2	Do you know that these deficiencies can be the cause of certain diseases?	**0.36**	0.18	-0.06
3	Have you (or your family members) already suffered from any deficiency due to a lack of these elements?	0.17	0.14	-0.01
4	Do you know that these nutrients can be enhanced in sorghum?	**0.56**	-0.01	0.03
5	Have you ever heard about bio-fortified sorghum?	**0.44**	-0.11	0.06
6	Do you know that Burkina Faso has subscribed to a local sorghum enrichment programme to fortify sorghum with vitamin A, zinc and iron?	**0.40**	-0.07	0.05
7	Do you think the bio-fortified sorghum programme is welcome?	-0.17	0.14	0.05
8	Do you think it's appropriate to improve the micronutrients in sorghum?		-no loadings	
9	Would you like to learn more about this bio-fortified sorghum programme?	-0.01	-0.26	0.01
10	I am regularly informed of the research on improved varieties	-0.05	0.26	**0.37**
11	I regularly participate in exhibition fairs of research findings	-0.07	0.07	**0.37**
12	I believe bio-fortified sorghum should be better explained to the producers by the relevant authorities	0.01	**0.49**	-0.11
13	The bio-fortified sorghum seed should be available at the same price as the local variety	-0.01	**0.50**	-0.14
14	I prefer to continue with the local variety	0.04	-0.10	**0.56**
15	I will produce bio-fortified sorghum provided the government agrees	-0.08	**0.33**	0.17
16	I have a bad experience with previously improved varieties of sorghum	0.05	-0.09	**0.53**
17	I will produce bio-fortified sorghum if the price is affordable	0.001	**0.35**	0.21
	Eigenvalues	2.92	2.75	2.20
	Accepted factor loadings[10]	>0.3		

Statements 1: Strongly disagree; 2 Disagree; 3 Neutral; 4 Agree; 5 Strongly agree.

4.3.3. Result of the Latent Class Model

The LCM was estimated using NLOGIT 5.0. We first specified the product attributes that influence the farmers' choice for biofortified sorghum. Secondly, we specified the

[10] In this study, the cutoff used to determine what coefficients were meaningfully weighted on a factor was 0,3. This is reported as a minimum in a review study on the use of exploratory factor analysis by Henson and Roberts (2006). While the more typical cutoff value is 0.4 , we opted for this minimum to get a richer description of the factors.

socioeconomic characteristics and motivational factors that could determine the class membership. In a first estimation, the CL model was used to assess the overall preference structure of the farmers without considering their personal characteristics. The result of the CL is presented in Table 4.4. It reveals that all the product attributes included in the model are significant utility parameters considered by the farmers in their choice decision. This, therefore, suggests that the farmers consider many attributes and often compare them before making decisions. For instance, compared to the seed source, the addition of micronutrients returns a higher utility for the farmers. It has a positive and very high significant effect on farmers' utility. Preference for the seed providers shows that farmers will favour in the first instance a public-sector seed source, before public-private partnerships, and a private sector. This is in line with earlier studies that the seed sector matters for transgenic crop adoption in SSA (Mabaya et al., 2015).

Farmers also made valuation on the maturity period, yield and seed cost. The expected days of maturity of sorghum have a negative and significant relationship with the farmers' choice. The negative coefficient is in line with the expectation that farmers would likely adopt a sorghum cultivar that is early maturing. Drought is arguable the major environmental challenge facing sorghum farmers in Burkina Faso, therefore, an early maturing attribute would be a high incentive to adopt the new biofortified seeds. The utility parameter of yield is positive and highly significant, indicating that the farmers have a clear preference for high yielding seeds. A positive but barely significant preference for yield has been reported for Burkina sorghum farmers by Adesina and Baidu-Forson (1995). Ascribing a higher utility for sorghum yield is expected. This is because the demand of food generally has increased, because of the increased population. While the poverty level is high with the poorest farmers not being able to purchase cereals, it is, therefore, plausible for farmers to prefer high yielding sorghum seed. Finally, the seed price attribute is negative and significant, indicating a preference for seed varieties with a lower cost. This is in line with economic theory and is expected because the majority of farmers in the study area practice seed saving, and those that purchase seed accessed it mostly from government agencies at lower price. Nevertheless, we can infer that the new biofortified variety may be able to compete with the local and improved variety if it is provided through a market penetration pricing strategy.

Table 4.4: Conditional Logit Representing Utility Derived from Sorghum Attribute

Utility parameter	Coefficient	Standard Error
Increased Micronutrients	3.3835***	0.1685
Seed price	-0.0008***	0.0006
Public seed source[1]	0.7164***	0.1088
Private seed source[1]	-0.6964***	0.1419
Yield	0.0069***	0.0004
Days to maturity	-0.0333***	0.0032
Probability of selecting an opt out alternative		
Alt 5: Preference for local seed	27%	
Alt 6: Abandon (GM) sorghum	0%	

[1]Compared to public-private partnership,
***, **, * = significant at 1%, 5%, 10% level

The second part of Table 4.4 shows the probabilities of selecting the opt-out alternatives. The result shows that on average, 27% of the farmers would prefer the local seed against the new variety. More so, with a 0% preference for alternative 6, we can assert that on average, 73% of the farmers sampled in our study may be willing to adopt a biofortified variety. CIRAD (2016) equally reported a 75% adoption for improved sorghum varieties in villages selected for the participatory sorghum breeding project in Burkina Faso. When we combine this result with our previous finding that 60% of farmers are indifferent to the source of their seed, we can confidently argue in line with Grabowski et al, (2016) that small scale farmers in Burkina Faso are not stuck in traditions, but compare the value of new technology with existing alternatives before making adoption decision.

4.3.4. Socio-economic and Motivational Factors Influencing Farmers Valuation

Although the result from the CL model is useful in determining the farmers' valuation of the new sorghum attributes, it does not however reflect the heterogeneity of preferences among respondents. The CL assumption that the utility is homogenous across all the farmers might not be true in our study. The LCM provides evidence for systematic heterogeneity in the preference structure of the sorghum farmers. To estimate this heterogeneity, the LCM was run several times with increasing number of segments and different combinations of segment membership variables. To identify the optimal number of segments, a balanced assessment of the Log-likelihood function, Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), and the Mcfadden pseudo squared (P^2) were considered following Kikulwe et al. (2011) and Birol et al. (2007).

Considering the information criteria in Table 4.5, the log-likelihood improved and P^2 increased as more parameters were added until they maximized in a model with 3 segments. This implied an optimization at this number of segments. To confirm this, the AIC and BIC decreased from the first segment but were minimized at 3. Therefore, a three-segment model was selected. The best fitting LCM included the following variables in the membership function: the farmers' attitude towards risk, the sorghum yield of farmers; and whether farmers save seed or not. Finally, a comparative summary statistic of the features of the segments was obtained. The segment probabilities of individual respondents were used to assign farmers to a given segment. A respondent is assigned to the segment where he scores the highest probability.

Table 4.5: Information Criteria for Determining the Optimal Number of Class

No. of Segment	Parameters	Log Likelihood	P^2	AIC	BIC
1	6	-878.8	0.3772	1769	1798
2	17	-795.3	0.5068	1617	1679
3	26	-742.9	0.5393	1537	1663
4	27	-764.1	0.5262	1582	1712

In the 3 segments model presented in Table 4.6, 31.2% of the respondents belong to segment 1, 14.1% to segment 2 and 54.7% belong to segment 3. The segment 3 is the reference, so the coefficients are normalized to zero to allow a comparative interpretation. The first part of the table presents the coefficients for the seed attributes, while the second part shows the class membership function. The third part is the description of individuals in the segment.

For segment 1, the utility coefficients reveal that farmers belonging to this segment have preference for sorghum seed with more micronutrients, lower price and higher yields. In terms of seed source, a higher preference is found for public seed providers compared to either a private or public-private partnership. Maturity period does not seem to be a significant determinant of choice for the farmers. Furthermore, the estimates from the segment membership function reveal that farmers who are more risk averse but produce relatively higher quantities of sorghum are more likely to belong to the segment. We label this segment "Micronutrient Preference Group" due to three reasons. First, the coefficient of the increased micronutrient attribute for this segment is much higher than that of the other segments. Second, when we normalized the utility parameters in this segment by price attribute, we observed that the segment members derive the highest utility from the increased micronutrient attribute. Third, the farmers in the group produce significantly higher quantity of sorghum than other groups. With proper information and awareness of its nutritive quality, this segment could be encouraged to adopt the new biofortified variety.

Segment 2 differs from 1 in many ways. For instance, in contrast to 1, the absolute value for the coefficient of the increased micronutrient attribute was quite small. The respondents show more preference for public seed sources and shorter day of maturity than for increased micronutrient. Furthermore, in the segment membership, we observe that farmers who practice seed saving culture and those that produce smaller quantities of sorghum are more likely to belong to this group. We label this group “Small Sorghum Producers Group” because of the following factors. First, the private seed source is not an important determinant factor in their choice. Second, they focus on the early maturing attribute, indicating possibility for subsistence cultivation. Finally, the seed saving culture and production of smaller quantity of sorghum are obvious characteristics of these farmers. A distribution agreement allowing seeds to be reused may influence this group to adopt the biofortified sorghum.

Finally, when normalized with the seed price attribute, farmers in segment 3 relative to those in segment 2, value increased micronutrient more and days to maturity less. The peculiar feature of segment 3 is that they attach higher utility to sorghum seed provided by a public-private partnership than other segments. Following Birol et al. (2011), the segment membership coefficients of the group can be interpreted as long as the other segments have the same signs. Consequently, farmers who take more risk are likely to belong to this group. Following the characteristics of risk averse farmers identified in PCA, this group of risk takers would likely be producing Bt cotton, and are less likely to be influenced by price or seed source. We labelled this group “Risk Takers”. They may show positive attitude towards transgenic sorghum variety, and would most likely be among the early adopters. They constitute a little above half of the farmers sampled (54.7%).

Table 4.6: The LCM estimate for transgenic sorghum seed attribute

	Segment 1 (31.2 %) Micronutrient Preference	Segment 2 (14.1 %) Small Sorghum Producers	Segment 3 (54.7 %) Risk Takers
Utility parameter: Biofortified sorghum seed attributes			
Higher Micronutrient levels	23.283*** (5.47)	2.5576**(1.082)	3.2506***(0.2879)
Seed price	-0.0047*** (0.001)	-0.0018***(0.0004)	-0.0010***(0.00012)
Public seed source[1]	5.1014*** (1.453)	2.0309***(0.5474)	0.2016(0.16577)
Private seed source[1]	2.4205*** (0.9192)	-2.7152(3.0654)	-1.0117***(0.2131)
Seed Yield	0.0385*** (0.0079)	0.0121***(0.0028)	0.0081***(0.00069)
Days to maturity	-0.0036 (0.0256)	-0.0459***(0.01614)	-0.0391***(0.00493)
Segment membership: Farmers characteristics			
Constant	30.719(0.118D+08)	4.0378(3.5584)	-
Risk averse- attitude	0.5025***(0.1909)	0.43557(0.6989)	-
Annual sorghum production	0.00668**(0.0028)	-0.0165**(0.0069)	-
Seed saving practice	-36.641(0.118D+08)	5.8351**(2.284)	-
Individual Features			
Total annual yield (kg/ha)***	846	676	783
Sorghum acreage (hectare)	1.61	1.58	1.58
Total acreage (hectare)	6.89	9.63	8.76
Age (average years)	44.6	43.8	43.8
Number of farmers	47	21	82

[1]Compared to public-private partnership,

***, **, * = significant at 1%, 5%, 10% level

4.3.5. Farmers Willingness to Pay for Attribute Changes

This section estimates the welfare measure for going from the current seed used by the farmers to the new biofortified variety. The welfare measure is the premium they are willing to pay for a change in attribute levels. The WTP reported in Table 4.7 was estimated from the utility parameter in the LCM. The WTP for changes in some product attributes whose coefficients are insignificant in the LCM were not reported in the table. Although the table showed the mean WTP for changes in different product attributes included in the choice set, in line with the objective of the research, we concentrate more on the farmers WTP for our attribute of interest, which is increased micronutrients.

The results show that generally, the farmers may pay premium for the new sorghum seed with extra micronutrients. However, the extra amount to be paid varies among the segments. For the Micronutrient Preference farmers, the mean WTP to go from a local sorghum variety to the biofortified variety is 4953CFA per kg. This implies that the farmers in this class would likely pay on average an additional 4953CFA per kg to get the new biofortified sorghum seed with higher micronutrient. The Risk Takers are willing to pay on average an extra 3251CFA per kg for biofortified seed with increased micronutrients. Finally, the Small Sorghum producers are willing to pay less than the two groups. Their WTP for a biofortified sorghum seed with increased micronutrients is estimated at 1421CFA per kg. This is however expected as most farmers in this class do not buy their seeds from the market but use saved seeds from previous planting seasons.

Table 4.7: Farmers Willingness to Pay for a Change in Attribute

WTP for	Class 1 Micronutrient Preference	Class 2 Small Scale Farmers	Class 3 Risk Takers
Extra Micronutrient	4953	1421	3251
Public seed source	1085	1128	-
Private seed source	515	-	1012
Higher Seed yield	8	7	8
Early maturing seed	-	26	39

Parameters in CFA per kg; Blank spaces are due to insignificant coefficient in LCM.

4.4 Conclusion and Recommendations

Transgenic biofortification is emerging as an alternative public health intervention project for the improvement of the nutritional status of people. However, none of such crops have been released to the farmers due to the controversies surrounding the process. In Burkina Faso, where transgenic biofortified foods may have important health benefits given the high frequency of MNM, biofortified seeds need to possess desirable attributes to be able to contend with the highly valued local variety. Far to provide an exhaustive answer at the dilemmas, our work focuses on investigating in ex-ante the market potential of the proposed transgenic biofortified sorghum by AHI. We employed a DCE to investigate the farmers' valuation of various attributes that could make up the biofortified seed as well identified the factors that influence the farmers valuation.

The results show that there is a promising market for transgenic biofortified sorghum in Burkina Faso, and the biofortified variety may be used as a veritable tool for reduction of MNM in the country. The findings from the DCE suggest that local farmers in Burkina Faso can change from traditional seed saving practices and are able to conduct a proper valuation of the attributes of the new products before making adoption decision. We showed that aside from the farmers that may still maintain a high penchant to the local seed variety, about 73% of farmers in the sample would be willing to cultivate the proposed transgenic sorghum variety. Nevertheless, the attributes of the new product should be significantly more appealing than the local variety for this market size to be achieved. Specifically, early maturation, higher yields, and lower prices would make these seeds more attractive.

Secondly, the LCM shows that there was heterogeneity in the preference structure of the farmers. The study identified three distinct classes of farmers based on their preference structure, the Micronutrient Preference Farmers, the Small Sorghum and the Risk Takers group. By segmenting our respondents into these 3 groups, we showed that those that have experience with first generation transgenic crops in the country (Bt cotton), are more likely to adopt the second-generation product. This segment otherwise known as the Risk Takers constitute a majority of the sample (55%), so we propose that they become the first market targeting group.

Finally, as a general implication for the development of the biofortified sorghum, we recommend that farmers should be carried along in the further development of the product. Adequate information should be provided to farmers, and if possible, the sorghum farmers' organizations should partner with AHI in the development of the new biofortified sorghum. Despite showing that farmers are willing to pay premium for the new biofortified seed, we hold that a market penetration strategy (subsidized price) is necessary to introduce the crop to farmers. We also recommend a strong government involvement in the development of the new product. The role of the government should among other things create awareness of the nutritional values of the new product, subsidize the product as well as participate in the eventual distribution of the transgenic seed.

PART FOUR: Bt maize Event

Chapter 5: Ex-ante Assessment of the Determinants of Farmers' Intention to Adopt Bt Maize in Kenya[11]

Abstract

Since the recent approval for limited environmental release during National Performance Trials in Kenya, the maize event MON810, a Bt maize variety, has reached the final stage before release for cultivation. This paper investigates farmers' knowledge and attitudes towards GM technology as well as their awareness and understanding to the objective of this specific maize event. The study also aims to identify the determinants of farmers' intention to adopt this GM maize variety. Based on a face-to-face survey, 150 farmers from the Western and Eastern regions of Kenya were randomly selected and interviewed. Findings from this study showed that in overall, farmers had poor knowledge as regards with the core concept of agricultural biotechnology and GM technology. Although the majority (85.3%) of participants were informed about the development of Bt maize, only 14% were aware about its main trait, which targets stem borer species. According to farmers opinions, stem borer attacks are more problematic in Eastern than Western region regarding the maize yield losses. Fall army worn (*Spodoptera frugiperda*) is pointed out by Western farmers as the most damaging insect. Consequently, the intention to adopt this GM variety was more positively expressed in the Eastern (88%) as compared to the Western (47%) regions. Although our binary logistic regression model showed that the number of stem borer species faced by farmers is the key factor of future adoption in both regions, important regional differences were found. In the Western region, older farmers are more likely to adopt GM variety than younger farmers, while the perception of the environmental benefit, due to the lower use of pesticides, is identified as a key determinant shaping Eastern region farmers' behavioral intention towards GM seed adoption. From a policy perspective, our study underlines the need for suitable communication channels on Bt and other GM crops to improve African farmers' awareness of the objective and impacts of their implementation.

Key words: Adoption behavior, Bt maize, GM technology, Agricultural Biotechnology, Kenya

---

[11] This chapter was based on: Edouard I. R. Sanou, Hans De Steur, Dorington O. Ogoyi, Godelieve Gheysen, Stijn Speelman. *Ex-ante Assessment of the Determinants of Farmers' Intention to Adopt Bt Maize in Kenya*. *In Trends in Biotechnology. (Under review)*

5.1. Introduction

Regardless of the large scale commercialization of genetically modified (GM) crops with improved agronomic traits around the world (ISAAA, 2017), the debate on GM technology continues to be present at different levels of the society (Blancke and Grunewald, 2017). Discussions target a variety of issues related to risk assessment (Ronca et al., 2017) regulation and policy decision making (Adenle et al., 2018; Azadi et al., 2017; Guehlstorf, 2008), impacts on the environment (Brookes and Barfoot, 2017), health and food security (Glass & Fanzo, 2017; Smyth et al., 2015; De Steur et al., 2014). Regarding the latter, there is a large body of research examining the economic benefits at farm level. Even though the evidence on yield effects is well established, as illustrated in several recent meta-analyses (Pellegrino et al., 2018; Klumper & Qaim, 2014), current adoption rates of farmers vary between and within countries (ISAAA, 2017) which points to a research need for explaining farmers' behavior (Zhang et al., 2017; Guehlstorf, 2008).

Farmers' adoption behavior towards GM technology has been widely examined, both in developed (Todua et al., 2017; Areal et al., 2011; Demont et al., 2008; Gyau et al., 2009; Van Scharrel and Van der Sluis, 2004) and developing countries (Sanou et al., 2018; Oparinde et al., 2017 ; Nyinondi et al., 2017; Autade et al., 2016; Schnurr and Mujabi-Mujuzi, 2014; Kimenju et al., 2011; Lewis et al., 2010). Regardless of the timing of the study, before (*ex-ante)* or after (*ex-post)* the introduction of a GM crop, research has reported key factors shaping farmers' (intended) adoption of GM crops, among which farm related factors (e.g. farm size, yield and farm income), technology related factors (e.g. perceived benefits and risks) and socio-economic determinants (e.g. gender, age, education level) (Breustedt et al., 2008; Sundig and Zilberman, 2001). For many determinants, however, study findings remain inconclusive. For instance, while some authors (Keelan et al., 2009; Fernandez-Cornejo and McBride, 2002; Marra et al., 2001) suggest that large-scale farmers were more likely to adopt GM crops, Chimmiri et al. (2006) as well as Darr and Chern (2002) report that farm size had no significant impact on GM adoption decisions. Different views concerning other factors, like education, age and gender, are discussed in various farmer studies (e.g., Todua et al., 2017; Keelan et al., 2009; Gyau et al., 2009; Van Scharrel, 2003, Fernandez-Cornejo and McBride, 2002; Darr and Chern, 2002).

Awareness of the GM technology, though indicated as a key factor in a recent *ex-post* analysis (Todua et al., 2017), has been hardly included in adoption research as a determining factor. Similarly, research on farmers' awareness of the objective of the targeted GM crop is scarce

(Johnson et al., 2009), especially in *ex-ante* studies (Edmeades and Smale, 2006). Regarding pest-resistant GM crops for instance, farmers' awareness of the targeted pests has not been accounted for as a potential determinant influencing their intention to adopt these crops or not.

Nevertheless, from a policy point of view, it is of uttermost importance to ensure that farmers' expectations match the target traits or objectives of a GM crop. This is especially the case for pest-resistant traits, since the pests dynamic has changed over time, e.g. due to global warming (Menéndez, 2007). Moreover, farmers' main concerns on GMOs revolve around the need for information on the one hand, and the role of governmental policies to respond to their interests on the other (Todua et al., 2017; Schnurr and Mujabi-Mujuzi, 2014; Lewis et al., 2010; Guehlstorf, 2008). Therefore, prior to the implementation of a GM technology, decision makers need to assess farmers' awareness in order to anticipate future farmers' opposition and potential misuse of the technology. In a study on GM cotton in Burkina Faso, for instance, it was shown that 81% farmers did not optimize their pest strategies when spraying cotton, owing to the miscommunication about the GM technology use (Sanou et al., 2018). This underlines the importance of a straightforward communication policy about the target objective of GM crops in order to better inform farmers when they decide on whether to adopt or not. As shown by Kotey et al. (2017) in South Africa, for example, awareness of the GM crop stewardship requirements is urgently needed to improve its management and exploit the benefits provided by the GM technology.

Building upon the aforementioned knowledge gaps, this paper presents an *ex-ante* study on farmers' awareness and intention to adopt a pest-resistant (Bt) GM maize in Kenya, where it is currently being tested in field trials. Thereby, it also looks at the misunderstanding of the GM technology and examines the factors influencing farmers' intention to adopt Bt maize.

5.2. Methodology

5.2.1. Background of the study

In 1999, the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI) launched the development of an insect-resistant GM maize variety (De Groote et al., 2003; Mwangi and Ely, 2001). Twenty years later, this crop has obtained approval for limited environmental release for National Performance Trials, the final stage before placing the product in the market for cultivation.

Through incorporating the modified gene (from a soil dwelling bacteria *Bacillus thurengiensis*) (Saxena and Stotzky, 2000) in local maize varieties, this GM maize specifically targets stem borer species, which are considered the main insect group causing maize yield losses in Kenya (De Groote et al., 2002). At economic level, 14% of annual maize yields in Kenya were estimated to be lost due to stem borer damage, which represents 0.4 million tons or US$ 25-60 million, enough to feed 3.5 million people per annum at per capita maize consumption of 125 kg (Odendo et al., 2003).

Given that maize yields in Kenya are among the lowest in the world (FAO, 2016) and the development of improved (hybrid) varieties failed to overcome stem borer attacks (Muhunyu, 2008), adoption of GM maize is expected to drastically increase the productivity. It has the potential to increase yields where the stem borers are a major constraint (Tende et al., 2010), as illustrated in South Africa (Gouse et al., 2006; 2005), which is the only sub-Saharan country currently growing GM maize (ISAAA, 2017). By commercializing such a GM maize crop in Kenya, decision makers expect to improve household income (with higher yield), reduce environment pollution (because of lower pesticide use) and improve farmers' health.

5.2.2. Survey sites

Maize is produced in six agro-ecological zones in Kenya (Figure 5.1). This study was conducted in Western and Eastern Kenya, involving four of the six agro-ecological zones: Highland Tropics & Moist Transitional (Western Kenya), which represents 80% of the maize production in Kenya, and Dry Mid-altitudes & Dry Transitional (Eastern Kenya), which has the lowest maize yields (Hassan, 1998). To reflect the share of production in both regions, respectively eight and four villages were visited in Western and Eastern regions. Villages hosting Kenya Agricultural Research Institute (KARI) stations were purposely excluded in order to get insights from less informed farmers.

5.2.3. Design of the questionnaire

A questionnaire was developed based on information obtained from scientific literature (Wang et al., 2017; Tefera et al., 2016; Mwangi and Ely, 2001; De Groote et al., 2011; 2003; De Groote, 2002; Hassan, 1998) as well as the official reports from research institutes in Kenya. To be able to achieve the aforementioned aims of this study, six sets of questions were identified and developed in the questionnaire. In table 5.1 below, the sets are described as well as the method used and the target groups. For instance, the first question set dealt with the characteristics of the households. In this set, the socio-economic determinants and the farm related factors were determined through the head of the household. In other sets, 4-, 5- and 7-point Likert-scales were used a measurement tool of, respectively, the perceived impacts of stem borer species, knowledge of agricultural biotechnology, perceptions of the advantages of GM maize and the intention to adopt it. The last set of questions focused on farmers' awareness of the drivers leading to the development of GM maize, the first outcomes from field trials and the preference towards the variety to transfer the Bt gene. This section makes a distinction between potential adopters and non-adopters to see whether or not the communication about the GM technology has impacted their decision to adopt the GM seed or not.

5.2.4. Data collection and Analysis

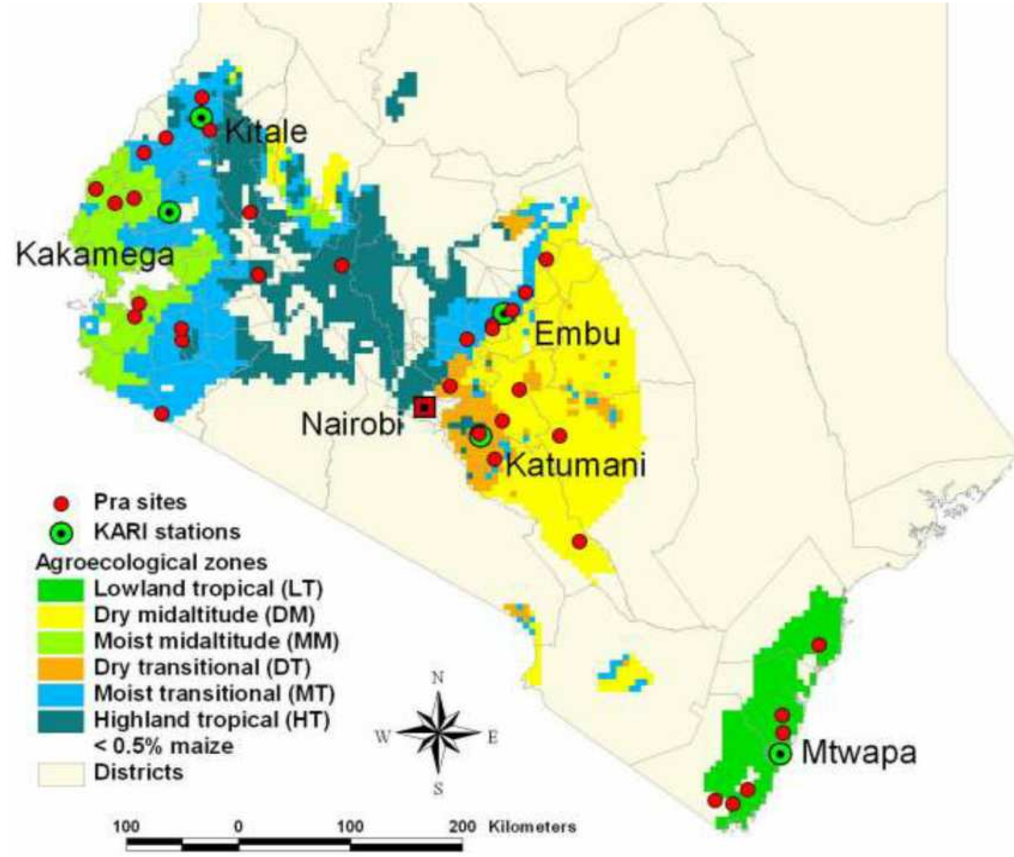
To get insights from farmers, a face-to-face interview was adopted along this survey conducted on April-May 2017 in Western and Eastern Kenya. A stratified sampling method was adopted in order to obtain a broad insight from diverse respondents taking into account gender, age, farm size and education level. A total number of 150 farmers were randomly selected in the Western (100 farmers) and Eastern (50 farmers) regions. Due to the dominance of the Western regions in maize production in Kenya, two-thirds of the respondents were sampled in that region. Each interview took about 45–60 minutes.

Data were analyzed using IBM SPSS statistics (version 22). The empirical analyses were made in multiple phases. In the first step, descriptive statistics were used to describe the socio-economic and farm characteristics of household. Then, a two-sample t-test was performed to compare the perceived impact of different stem borer species within the study regions. In the following step, a Principal Component Analysis (PCA) with varimax rotation was carried out in order to obtain factors that reflect the statements on farmer perceptions of the advantages of GM maize. The consistency of the scale of each factor was assessed through Cronbach Alpha. In the final step, bivariate (cross-tabulation) and multivariate (binary logistic regression) analyses were carried out to identify, respectively, significant differences between potential adopters and non-adopters and significant determinants of GM technology adoption.

Table 5.1: Design of the questionnaire

Question sets	Description	Method/tools	Target group
1. Household characteristics	Socio-economic determinants (gender, age, education level, etc.) and farm related factors (farm size, type of variety, yield, seed varieties, formal agricultural training, share/purpose of maize production)	Based on farmers declaration	All farmers
2. Farmers' perceptions of the insect damage	Identification of the most damageable insect groups in maize production	Self-evaluation by farmers	All farmers
	Perceived impacts of stem borer species	4 point Likert-type scale (from 0: not at all a problem, 1: minor problem, 2: moderate problem and 4: serious problem): 4 pictures of the main stem borer species	All farmers
	Identification of the number of stem borer species faced at farm	Based on farmers' valuation of the 4 stem borer species impacts	West and East regions
3. Farmers' knowledge of agricultural biotechnology and awareness of GM maize objective in Kenya	Core concept of agricultural biotechnology, GM technology, Bt maize field trials in Kenya and refuge strategy	5 point Likert-type scale (from 0: totally unclear, 1: unclear, 2: more or less clear, 3: clear and 4: totally clear)	all farmers
	Awareness of the GM maize event in Kenya, sources of awareness, awareness of the framework of the GM event and the objective	Based on farmers' declaration and multiple choice responses (2 statements)	All farmers
4. Farmers' perceptions of the advantages of GM maize	Statements of GM maize as a techno to improve maize yield, farmers' wellbeing, environmental and health benefit	7 point Likert-type scale (from 1=Strongly disagree,… 4= Neutral, …to 7= Strongly agree) (7 statements)	All farmers
5. Farmers' intention to adopt a GM maize variety that targets stem borer species	Intention to adopt or not the GM maize variety after awareness of the main objective of the GM variety being developed (protection against stem borer)	7 point Likert-type scale (from 1=Strongly disagree,…. 4= Neutral, …to 7= Strongly agree)	Potential adopters and non-adopters
6. Farmers' awareness of the drivers and field trial outcomes of GM maize and preferences for the variety to develop	Do farmers know why this decision was taken? Do they agree with that? Which variety do they prefer for transfer of the Bt gene	Agree/Neutral/Disagree: 6 statements	Potential adopters and non-adopters

Figure 5.1: Sites of the study



Source: International Maize and Wheat Improvement Centre (CIMMYT) and Kenya Agricultural Research Institute (KARI)

5.3. Results

5.3.1. Socio-economic and farm characteristics of household

Table 5.2 presents the socio-economic and farm characteristics of the households. From the 150 farm household heads interviewed, 122 (81.3%) were males, and the average age was 44.7 years. The level of education was quite high, with 88.7% having received a form of formal education (e.g., primary, secondary and above). The mean farm size per household was 7.9 acre from which on average 5.5 acre (69.6%) was allocated to maize production. The Western region displayed the highest share of maize plots (75.5%). The average maize production amounts 17.4 bags/acre (1bag=90Kg). As expected, the Eastern region faced the lowest yield with only 4.7 bags/acre associated to the highest use of saved seed (66%) from previous harvest. This lower yield in the Eastern region confirmed previous studies qualifying the Western region as the maize attic in Kenya (De Groote 2002, Hassan 1998). Maize is mainly cultivated for the local market in Western Kenya (88.3%). Most farmers (89.3%) used hybrid maize seeds which is consistent with a recent Kenyan maize study of Wang et al. (2017). However, about 22% in Eastern region indicated their preference for Open Pollinated Variety (OPV) seeds.

Table 5.2: Socio-economic and farm characteristics of household

Parameters	Total (N = 150)		Western (n = 100)	Eastern (n = 50)
	Mean	**Std. Dev.**	**Mean**	**Mean**
Age	**44.7**	**11.2**	43.2	47.6
Total acreage (acre)	**7.9**	**7.8**	9.8	4.1
Maize acreage (acre)	**5.5**	**3.9**	7.4	1.6
Average yield (bag/acre)	**17.4**	**9.9**	23.8	4.7
	N	**%**	**%**	**%**
Gender				
Female	**28**	**18.7**	17	22
Male	**122**	**81.3**	83	78
Education (% of literacy)	**133**	**88.7**	89	88
Formal agriculture training	**80**	**53.3**	67	26
Type of Variety				
Hybrid	**134**	**89.3**	95	78
OPV	**16**	**10.7**	5	22
Seed Provenance				
Recycle (saved seed)	**39**	**26**	6	66
Commercial	**111**	**74**	94	34
Share of Maize (% of acreage)		**69.6**	75.5	39.02
Purpose of Maize production				
Own consumption	**49**	**32,7**	11.7	64.4
For Selling	**101**	**67.3**	88.3	25.6

1 ha = 2.47 acre; 1bag of maize = 90 kg;
Std. Dev.: Standard Deviation; OPV: Open Pollinated Variety

5.3.2. Farmers' perceptions of stem borer issues in maize production in Kenya

Four insect groups were identified by farmers when listing the most damaging insects in maize production in the East and West of Kenya (table 5.3). According to the farmers, stem borer attacks were found to be more problematic in the East (100%) than in the West (42%) regions, while army worm (*Spodoptera frugiperda*) control appeared to be the main concern in Western region (93%). In both regions farmers reported more or less the same level of injuries regarding aphid and weevil attacks.

Regarding the perceived impact of stem borer species at farms, results of the independent samples t-test showed significant differences between the two regions. According to farmers *B. fusca* has emerged as the most damageable in both regions *C. partellus* was viewed by Western farmers to have minor impacts whereas farmers in Eastern regions perceived its impact varying form moderate to serious. *E. saccharina* and *S. calamisti* were only observed in the Eastern region, but they were not found to be a problem in maize farms. On average, about 1 to 2 stem borer species were generally affecting, respectively, Western and Eastern farms.

Table 5.3: Presence of insect groups and perceived impact of stem borer species in maize production in Kenya

	Western (N= 100)		Eastern (N = 50)		
	N	**%**	**N**	**%**	χ^2
Insect groups					
Army worms	93	93	24	48	χ^2 (1) = 39.34, $p < 0.05$
Aphids	36	36	17	34	χ^2 (1) = 0. 58, $p > 0.05$
Weevils	40	40	22	44	χ^2 (1) = 0.22, $p > 0.05$
Stem borers	42	42	50	100	χ^2 (1) = 47.28, $p < 0.05$
	Mean	**SD**	**Mean**	**SD**	***t*-test**
a. Perceived impact of stem borer species					
Chillo partellus	1.2	1,4	2.7	0.5	-7.1***
Bussuola fusca	2.6	.9	3.0	0.0	-3.3***
Eldana saccharina	.0	.0	0.2	0.6	-3.3***
Sesamia calamisti	.0	.0	0.5	1.1	-4.6***
b. Number of stem borer species at farm	1.3	.64	2.3	.64	$p < 0.05$

Perceived impact based on a 4-point Likert-scale: 0=not at all a problem, 1=minor problem, 2=moderate problem, 3=serious problem. Levels of statistical significance: * $p<0.05$, ** $p<0.01$ *and* *** $p<0.001$
SD: Standard Deviation.

5.3.3. Farmers' knowledge of agricultural biotechnology and awareness of the GM maize event in Kenya

The majority (85.3%) of the participants were aware about the GM maize trials in Kenya (table 5.4). Five sources (friends, radio/TV, newspapers and extension officers) were identified through which farmers were informed about this variety. Radio/TV (53.1%) was shown to be the principal source by which most of respondents became aware of the GM event. About 10.2% of farmers were informed through others sources such as online press, workshops or conferences.

Regarding the framework monitoring the GM maize development and the target objective, most participants (68%) were aware that the GM maize was developed through a collaborative partnership, while 71.3% misunderstood the target objective of the GM technology. Only 21 (14%) of the farmers knew that GM maize is targeting the stem borer species while 62 (41.3%) thought the maize was protected against all insects and 22 (14.7%) of respondents had no idea about this.

With respect to farmers' knowledge of agricultural biotechnology, only 32 of them were able to express their understanding. Their understandings on the core concept of agricultural biotechnology and the trait of the soil bacterium (Bacillus *thuringiensis*) were unclear. In the status of GM variety field trials, the information gave by farmers about the first outcomes of field trial were totally unclear. As to the implementation of refuge strategy, none of them were aware.

Table 5.4: Awareness of the GM maize event and Knowledge of agricultural biotechnology

1. Awareness of the ongoing GM event (n = 50)	**N**	**%**
yes	128	85.3
No	22	14.7
2. Sources of information (n = 128)		
friends	58	45.3
Radio/TV	68	53.1
News paper	45	35.2
Extension officers	41	32
Others (internet, workshop, conferences, etc.)	13	10.2
3. Awareness of the GM event framework (n = 150)		
Kenya research only (Public)	13	8.7
Collaborative (Private-Public) Partnership*	102	68
Private research center	13	8.6
No idea	22	14.7
4. Awareness of the GM objective (n = 150)		
Target all kind of insects	62	41.3
Target post-harvest pests	45	30
Target stem borer species*	21	14
No idea	22	14.7
5. Knowledge of Agricultural Biotechnology (n = 32)	**Mean**	**SD**
Core concept agricultural biotechnology	1.8	1.58
Trait of *Bacillus thuringiensis*	1.7	1.57
Status of GM maize field trial in Kenya (findings)	1.3	1.42
Implementation of refuge strategy	0.5	1.13

Note: Knowledge of agricultural biotechnology is based on a 5-point Likert scale (0: no idea, 1: totally unclear, 2: unclear, 3: More or less clear, 4: clear, 5: totally clear)
*reflects current situation

5.3.4. Farmers awareness of the perceived effectiveness of GM technology

Table 5.5 provides the results of a principal component analysis on the seven statements pertaining to GM technology advantages. The three-factor solution explained 86.5% of the variance in the original data (with factor loadings above 0.7). Factor 1 includes three statements that refer to the improvement of farming systems. By summating the means of the three statements belonging to factor 1, results showed that farmers partially agreed or agreed with the advantages related to adopting GM maize variety. The second factor, labelled environmental benefits, included two statements. Farmers agree that the lower use of pesticides owing to the adoption of insect-resistant variety in maize production will preserve the environment. The third factor relates to the trait of the GM variety in development in Kenya. Farmers partially agreed with the main objective of the GM variety stating that stem borers are part of the main concerns hampering maize yields in Kenya. Subsequently, farmers show a high degree of agreement on the lack of a suitable integrated pest management of stem borer species.

The reliability of each factor was assessed using Cronbach's Alpha α. All of them, i.e. the improvement of farming systems ($\alpha = 0.83$), the environmental benefits ($\alpha = 0.98$) and the target of GM technology ($\alpha = 0.81$), had sufficient internal reliability consistency.

Table 5.5: Farmers' perceptions of the advantages of GM maize

	FL	Mean	SD
Factor 1: "Farming systems improvement," Cronbach Alpha: .83			
I am confident that growing a variety which controls stem borers in maize production could be a way to improve my yield	.905	5.85	1.13
Growing a variety controlling stem borers will not change anything in my farming practices regarding human labors [R]	.866	5.85	1.13
I do believe that this variety, with the lower use of pesticide could provide a positive health impact to me and my family as well as my livestock when feeding in maize fields	.759	5.53	1.54
Factor 2: "Environment benefit," Cronbach Alpha: .98			
The environment (e.g. water sources) is not affected by the quantity of insecticides used in my maize fields [R]	.921	6.03	1.25
Maize production does not require such quantity of insecticides, so there is no risk of negative impact in my environment	.915	6.04	1.20
Factor 3: "GM variety trait," Cronbach Alpha: .81			
Stem borer control is not the main concern for me in my maize field so that this variety should not be a priority [R]	.880	5.25	1.28
The current integrated pest management towards stem borers control works well so that we don't need this insect resistant variety [R]	.910	5.92	1.21

[R] means item is reversed scored; Seven Likert-scale: 1=totally disagree, 2=disagree, 3 = partially disagree, 4 =neutral, 5=partially agree, 6=agree and 7=totally agree; FL: Factor Loading; SD: Standard Deviation.
Note: Factor structure based on factor analysis (principle component analysis). Explained Variance: 86.5%, KMO: 0.55, Bartlett's Test of Sphericity: χ^2 (21) = 853.9, p = 0.000.

5.3.5. Factors influencing farmers' intention to adopt GM maize seeds

To understand which factors influence farmers' decisions to adopt Bt maize, a binary logistic regression model was estimated (table 5.6). The model included intention to adopt as a dependent variable, using a binary variable (non-adopter, adopter), and the socio-demographic and farm characteristics variables as well as the factors extracted from the PCA results as independent variables. The intention to adopt was divided in potential non-adopters and adopters. Our data shows that 67% of farmers are willing to grow GM maize. With a share of 88% of farmers, intention to adopt is substantially higher in the Eastern region as compared to the Western region (47%).

The binary logistic regression model revealed that three variables (age, number of stem borer species faced, environmental benefits) significantly and positively influence farmers' decisions to adopt an insect-resistant variety targeting stem borers. The largest odds ratio was obtained for the number of stem borer species. A farmer facing attacks from more than one species in their maize plot is seventeen times more likely to adopt the GM variety than a farmer with maximum one stem borer species affecting the maize production. Older farmers (≥ 50 years) are three times more likely to grow GM maize when compared to farmers below 50 year old. Perceptions on environmental benefits associated with the lower use of pesticide also captured potential adopters' interest as illustrated by a positive and significant p-value ($p = 0.005$).

When looking at the results of the binary logistic regression model comparing the Western and Eastern regions, two independent variables (age and perception of environmental benefits) were found to be significantly influencing farmers' intention. While older farmers (≥ 50 years) are four times more likely to adopt GM maize in the Western region ($p = 0.017$), environmental benefits of adopting GM seed significantly influences ($p = 0.011$) Eastern farmers with a higher odds ratio (25.3). Given that in the Eastern region all farmers face more than one stem borer species and the plot allocated to maize production was not above 5 acres, the two variables (age and farm size) were excluded in the Eastern regression model.

Table 5.6: Determinant factor influencing farmer intention to adopt by binary logistic regression

	All (N = 150)		West (n = 100)		East (n = 50)	
	N	%	N	%	N	%
Intention to Adopt						
Non-adopter (0 = 1-4)*	53	39.3	53	53	6	12
Adopters (1 = 5-7)*	91	60.7	47	47	44	88
Variables	**OR**	***p-value***	**OR**	***p-value***	**OR**	***p-value***
Gender						
Female (ref)	1					
Male	.7	.57	.3	.18	1.8	.70
Age						
< 50 years (ref)	1					
≥ 50 years	**3.4**	**.015**	**3.9**	**.017**	.8	.87
Farm Size						
≤ 5 acres (ref)	1					
> 5 acres	.6	.42	1.4	.65	-	-
Education						
Illiterate (ref)	1					
Literate	1.01	.98	.8	.74	1.5	.9
Number of stem borers species faced						
≤ 1 species (ref)	1					
> 1 species	**17.2**	**.000**	**11.7**	**.000**	-	-
Farm improvement (F1)						
Disagree (ref)	1					
Agree	2.1	.21	2.4	.17	.000	.9
Environmental benefit (F2)						
Disagree (ref)	1					
Agree	**5.9**	**.005**	1.9	.48	**25.3**	**.011**
GM maize trait (F3)						
Disagree (ref)	1					
Agree	.7	.63	.40	.26	12.2	.19

Dependent variable "Intention to adopt" is dummy coding: 0 = (1=totally disagree, 2=disagree, 3=partially disagree, 4=neutral); 1 = (5=partially agree, 6=agree, 7=totally agree). OR: Odds Ratio; (Ref): stands for reference category. Statements of each factor extracted from the PCA (F1: Factor 1; F2: Factor 2; F3: factor 3) were scored and dummy coding (0: disagree, 1: agree).
Note: Nagelkerke R^2: 0.495; Cox and Snell R^2: 0.366

5.3.6. Farmers' awareness of the GM maize drivers and preferred GM variety

To determine whether awareness of the drivers of the GM event (BT maize) in Kenya, as well as of the first outcomes of the GM maize field trials, and the preferred variety shape farmers' behavior, a comparison was made between potential adopters and non-adopters (table 5.7).

Results related to the first item, “stem borer damages”, confirmed that the majority of potential adopters perceive stem borer issues as a main concern when compared to non-adopters. Consequently, yield losses were attributed to stem borer attacks. With respect to the second item, labelled “perceived effectiveness” of the GM variety being developed in Kenya, most potential adopters and non-adopters were not aware about the outcomes of the field trial. Similarly, in the last item (“preferred GM variety”), the majority of adopters and non-adopters shared the same viewpoint, namely the insect-resistance gene should be transferred to a hybrid variety. In other words, they prefer hybrid above open pollinated varieties.

Table 5.7: Farmers' awareness of the GM maize drivers, field trial outcomes and the preferred GM variety

		Disagree		Not sure		Agree	
Item 1: Stem borers as damaging insects		**N**	**%**	**N**	**%**	**N**	**%**
a. Stem borers have been found as the main predators hampering maize production in Kenya	Adopters	-	-	13	8.7	**78**	**52**
	Non-Adopters	**42**	**28**	17	11.3	-	-
b. Studies showed that stem borers damages could vary from 15 to 45% maize yield losses during an agricultural campaign	Adopters	-	-	5	3.3	**86**	**57.3**
	Non-Adopters	-	-	**51**	**34**	8	5.4
Item 2: Perceived effectiveness of GM variety							
c. First outcomes from GM maize trial testing in Kenya showed that the variety developed controls stem borers	Adopters	-	-	**78**	**52**	13	8.7
	Non-Adopters	10	6.7	**49**	**32.6**	-	-
d. Technology developers assumed that the control of stem borers could improve the yield gain up to 30%	Adopters			**79**	**52.7**	15	10
	Non-Adopters			**59**	**39.3**		
Item 3: Preferred GM variety							
e. Recent studies conducted by assessing farmers' preferences towards hybrid or open pollinated variety demonstrated that farmers have more interest in hybrid variety	Adopters	5	3.3	-	-	**86**	**57.3**
	Non-Adopters	9	6	2	1.4	**48**	**32**
*f. To guarantee success to GM technology, the gene of *Bacillus thuringiensis* should be incorporated into open pollinated maize seeds	Adopters	**86**	**57.3**	-	-	5	3.3
	Non-Adopters	**50**	**33.4**	-	-	9	6

χ^2 a (2) = 119.13, p = 0.000 ; χ^2 b (1) = 100.24, p = 0.000 ; χ^2 c (2) = 23.88, p = 0.000 ; χ^2 d (1) = 10.81, p = 0.001; χ^2 e (2) = 7.43, p = 0.02; χ^2 f (1) = 0.22, p = 0.04

5.4. Discussion and conclusion

5.4.1. Farmers' knowledge of agricultural biotechnology and GM technology in Kenya

Overall, farmers in our survey presented a poor knowledge of the core concepts of agricultural biotechnology as well as on the GM technology use. Similar findings of such a knowledge gap were reported in the ex-ante study conducted among farmers in Tanzania (Lewis et al., 2010). Although selected farmers presented a high level of literacy (88.7%) coupled with an effort of communication by the technology developers, the status of the field trials and the term refuge area were not clear to many farmers. This lack of knowledge of refuge strategy was also reported in Burkina Faso, even several years after the implementation of Bt cotton (Sanou et al., 2018). Nonetheless, our data showed that the majority (85.3%) of farmers were aware about the development of insect-resistant maize, with even 68% being aware of the collaborative partnership for its development.

5.4.2. Misunderstanding of the GM maize variety objective in Kenya

Even though communication efforts on the GM maize development (via radio, TV, newspapers, etc.) were mentioned by the farmers, their understanding of the objective of the introduced trait (*Bacillus thurengiens* toxin) was much lower, as only 14% of them correctly pointed out stem borer species as the target of Bt maize. More than 70% of farmers expected this variety to be able to control all kinds of insects as well as post-harvest pests. This misunderstanding could be related to poor GM technology communication as also pointed out in a recent ex-ante study of Schnurr and Mujabi-Mujuzi (2014) on Ugandan farmers. They argued that using sources such as Radio/TV and newspapers in GM crop communication will be geared towards elites, such as members of parliament, high-ranking civil servants and media representatives, by which farmers could misunderstand the content of the delivered message. Therefore, it is important to organize the communication in a straight-forward manner that allows farmers to improve understanding and participate in this contentious debate (Ezezika et al., 2012; Lewis et al., 2010). Misunderstanding of the GM technology objective might also lead to the misuse of GM seeds, as shown in recent evidence from the Bt cotton case in Burkina Faso (Sanou et al., 2018).

5.4.3. Demand for insect-resistant variety in Kenya

The assessment of the most damageable insects in maize production indicated that two different insects groups hamper maize yields in the two regions: fall army worms in the West and stem borers in the East. Given that Bt maize only targets stem borer species, farmers in the Eastern regions, where maize yield is lower and awareness of the objective of Bt maize is higher, are considered as the key beneficiaries of this technology. They also tend to have more insect species affecting their maize plots as compared to the farmers in the West. In general, two main species of stem borers (B. *fusca* and C. *partellus*) were identified by farmers, in line with previous studies in Kenya (De Groote et al., 2011; 2003; Hassan, 1998). Besides, the specie B. *fusca* was pointed out as the most damageable insect in which seems to be inconsistent with De Groote et al. (2002), which report that this specie was mostly observed in the Western region. A change in pests dynamic might account for this, which is partially a consequence of a global warming (Sangle et al., 2015).

Overall, the development of the insect-resistant maize variety was positively perceived by all farmers, in line with the presence of insect damage in maize production. However, our data suggests that a variety that targets only stem borer species, like the Bt maize under investigation, will be most valuable in the Eastern region.

5.4.4. Factors influencing farmers' intention to adopt GM maize

Based on the assessment of the impact of stem borer species, the Eastern region presented a relatively higher potential in the adoption of Bt maize variety (88%) compared to the Western region (47%). In general, three factors (age, number of stem borer species and environmental benefits) were shown to influence farmers' intention to adopt. The number of stem borer species was found to be the main determinant factor stating that farmers facing more than one stem borer species were more likely to adopt Bt maize. Consequently, this confirms the difference between Eastern and Western regions regarding the potential adoption of a GM variety targeting stem borer insects due to the average number of stem borer species affecting both areas. Regarding the socio-demographic profile, our model suggests that older farmers were four times more likely to adopt such GM variety in Western region (where the stem borer issues were weakly perceived). The effect of age is inconsistent with most of the previous studies on GM technology adoption (Todua et al., 2017; Chimmiri et al., 2006; Fernandez-Cornejo et al., 2005; Alexander and Van Moller, 2005), who indicate that younger farmers were more likely to adopt GM varieties. Although army worm was pointed as the most damageable insect by most Western farmers (93%), many older farmers still remembered the damage of stem borers in the previous years, which may account for their larger share of farmers willing to adopt Bt maize in the future. Moreover, it confirms the trend of an increase in fall army worm issues that has emerged in the past years. The variables gender, education level and farm size had not significant impact in farmers decision to adopt GM maize in Kenya. For gender and education, our results are in line with those of Keelan et al. (2009) as well as Darr and Chern (2002). The positive impact of large scale farmers (Fernandez-Cornejo and McBride, 2002; Marra et al., 2001) was not confirmed in our study, most likely because stem borer issues were highly prevalent, regardless of the size of the farm.

Regarding farmers' perceptions pertaining to the adoption of the insect-resistant variety being developed, environmental benefits of lowered pesticide use had a positive influence in Eastern region. This could be related to the fact that the region is a rice growing area (based on traditional irrigation). Similar positive perceptions of Bt cotton cultivation with less use of pesticide was reported by Burkina Faso cotton producers (Sanou et al., 2018).

Regardless of the determinants of farmers' intention to adopt GM variety, awareness of the objectives of the improved trait (here, control of stem borer) seems to be crucial. Therefore, potential adopters and non-adopters presented opposite views considering the share of stem borers in maize yields losses. When comparing their views on the current field trial outcomes of the GM maize, both the potential adopters and non-adopters were hardly aware about the improvement of maize yields due to stem borers control. As such, awareness of the ongoing field trial did not influence farmers' decisions. Nonetheless, all the participants, regardless of whether they were intended to adopt or not, showed a preference for developing a GM hybrid variety instead of GM open pollinated variety. Similar preferences for hybrid varieties were reported in a recent ex-post studies (Wang et al., 2017; Mathenge et al., 2014).

5.5. Recommendations

The purpose of this study was to get insights from farmers on the GM maize event in Kenya. While looking at farmers mainstreaming in this event, the study determined the key factors influencing farmers' intention to adopt the GM maize targeting stem borer species.

Building upon the findings of this study, two main recommendations can be formulated in the light of policy and future research:

- The reinforcement of communication channels about GM technology, and its objective in particular, tailored towards farmers, as previously advocated by Guehlstorf (2008) as a way to improve farmers' awareness, and to avoid the misunderstanding and misuse of the GM seeds.
- The re-mapping of the distribution of stem borer species and others damageable insects (such fall army worm) in order to deploy the most needed GM varieties where it is needed, i.e. in line with farmers' preferences and needs. The upsurge of army worm insects in Western Kenya, for instance, sparked the need of a re-assessment of pest

dynamics in maize production and, related to this, the impact of global warming (Netherer and Schopf, 2010).

PART FIVE: GENERAL CONCLUSION

Chapter 6: Conclusion

The overall objective of this doctoral dissertation was to understand the farmers' perspectives on agricultural biotechnology in Sub-Saharan Africa. This research was inspired by the observation that farmers' voice was seldom accounted for in the fierce ongoing debate concerning GM technology uptake in Sub-Saharan Africa. In this thesis, farmers' perspectives on GM crops were analyzed for three specific GM crop events (Bt cotton, biofortified sorghum and Bt maize). The study was carried out in West (Burkina Faso) and East Africa (Kenya).

In this concluding chapter I will come back on the research questions identified in the introduction chapter, and I will discuss the general implications of my findings, will make some recommendations and reflect upon the limitations of this study as well as on future research questions inspired by the current research.

6.1. Recapitulation of research questions

This dissertation tried to find answers to twelve research questions, that were developed in line to fill the existing gaps in the GM technology literature in the context of Sub-Saharan Africa. Considering the three GM crop events investigated, the recapitulation of research questions is addressed as follows below.

6.1.1. Bt cotton event: research questions RQ1, RQ2, RQ3, RQ4 and RQ5

The first four research questions were explored in chapter 2.

RQ1 What is the level of understanding and knowledge among cotton farmers in Burkina Faso about the core concepts of biotechnology and more specifically, Bt-technology?

RQ 2 What are the perceptions of cotton farmers in Burkina Faso towards Bollgard II®?

RQ3 What is the impact of the implementation of Bollgard II® on the pest management practices applied by cotton farmers in Burkina Faso?

RQ 4 How do cotton farmers evaluate the recent decision by government in Burkina Faso to suspend cultivation of Bollgard II®?

Chapter 2 highlighted farmers' experience with Bt cotton in Burkina Faso. It provided insights towards farmers' understanding and perceptions about the implementation and the use GM of technology in cotton production. In addition, farmers opinions in the recent decision endorsed by the Burkina Faso government to suspend Bt cotton seed was analyzed in this chapter. Findings from chapter 2 showed that:

- The knowledge level of farmers concerning biotechnology in general and Bt-technology more specifically is limited and depends on their education level and their role within the GPC[12].
- The regulatory oversight for the implementation of Bt-technology is insufficient. The risks associated to a non-implementation of a refuge strategy was ignored by both farmers and fieldworkers.
- Farmers' knowledge about suitable pest management strategies is low. The specific recommendation to apply two late insecticide sprays to control aphids and jassids was not implemented.
- Even though different farming groups appreciate the income gain generated by Bollgard II® cotton adoption differently, the study found that the majority of the farmers were satisfied. Further investigation concerning the satisfaction with the Bt seed pricing policy revealed that there was a large divergence between farmers organization and their base.
- Finally, the government decision to forsake the production of Bollgard II® cotton in Burkina Faso was badly perceived by the majority of the farmers.

Regarding the key role played by the education level, this finding is in accordance with previous studies (Todua et al., 2017; Lewis et al., 2010) which found that the level of education was a determining factor shaping farmers' awareness about GM technology. Moreover, this study supports the concern put forward by Renaudin et al. (2012) linked to the limited economic benefit generated by Bt cotton for smallholder farmers in Burkina Faso owing to the high seed price per hectare.

Research question five (RQ5) was examined in chapter 3.

RQ 5 To what extent are the current characteristics of Bt cotton in line with famers' preferences?

In chapter 3, five key attributes related to cotton were used to determine farmers' preferences. Using a discrete choice experiment it was shown that all the attributes were factors determining farmers' preferences for cotton varieties. Overall, findings of chapter 3 suggest that preferences of farmers in Burkina Faso are mainly shaped by the economic returns, the yields, the seed costs

[12] GPC: Groupement de Producteurs de Coton (cotton farmers group)

and the pesticide use requirements. The current development of the cotton seeds through a public private partnership was found suitable for the majority of farmers. Similar studies in Burkina Faso on farmers' adhesion to the Bt seed source was previously reported (Méda et al., 2018; Dowd-Uribe, 2014).

6.1.2. Biofortified Sorghum event: research questions RQ6, RQ7 and RQ8

The chapter 4 was developed following three research questions such as:

RQ6 What is the level of knowledge among farmers in Burkina Faso about micronutrient deficiency and transgenic biofortification?

RQ7 How do farmers in Burkina Faso value various sorghum seed attributes?

RQ8 How do characteristics of farmers influence farmers' preferences for sorghum attributes?

In this chapter, first farmers' awareness about micronutrient deficiency was assessed. To assess the preferences, a discrete choice experiment including six potential attributes of sorghum was developed. A latent class model was used to study farmers' preference for sorghum varieties. The findings of chapter 4 mainly revealed that:

- the awareness of farmers on the micronutrient deficiency issue was proven but there was limited knowledge on transgenic biofortification;
- micronutrient content, price and yield are significant determinants of the preference of farmers for sorghum varieties;
- the seed sector and seed saving activities matters are a key factor in the acceptance of transgenic sorghum;
- overall more than 60% would be willing to cultivate a transgenic sorghum variety.

6.1.3. Bt maize event: research questions RQ9, RQ10, RQ11 and RQ12

The last four research questions were explored in chapter 5.

RQ9 To what extend are farmers aware about the development and the implementation of GM technology in maize production in Kenya?

RQ 10 How is farmers' understanding about the objective of this technology?

RQ11 What determines farmers' intention to adopt a GM maize variety in Kenya?

RQ 12 What are the key differences between farmers from the Western and Eastern regions of Kenya?

In chapter 5, *ex-ante* farmer research was conducted to evaluate the potential of Bt maize in Kenya. The assessment of socio-economic determinants was considered in this GM event as required following the Cartagena protocol. This chapter also determines farmers' intention to adopt GM maize variety and identifies the keys differences between Western and Eastern regions farmers. Findings of chapter 5 could be summarized as follow:

- Only few Kenyan farmers (14%) correctly associate Bt maize with stem borer.
- There are regional differences in perceived stem borer impacts and intention-to-adopt.
- The number of stem borer species is the key factor for the future of Bt maize.

Findings of this chapter suggest that additional communication efforts are needed to reverse incorrect perceptions about Bt maize.

6.2. Comparative discussion on farmers' perspectives on different GM crop events

6.2.1. Comparing the perspectives on GM cotton and biofortified sorghum attributes

The first generation or wave of new agricultural biotechnology contained input traits such as herbicide and pest tolerance, offering advantages to farmers in the production phase without changing the final product. The second generation of genetic modifications focuses on output traits such as improved nutritional features and processing characteristics. While there has been quite some attention for the attitudes of consumers towards GM crops, with a number of authors even comparing the attitudes of consumers towards first and second generation GM crops (eg Klervi et al., 2007; Stewart and Mc Clean, 2005), the preferences and acceptance by farmers have been researched far less (see eg. Chong, 2005; Kondoh and Jussaume, 2006; Birol et al., 2008; Areal et al., 2011; Skevas et al., 2012; Maia and da Silveira, 2016), with no studies among sub Saharan African farmers.

In this PhD, I specifically studied the preferences of a group of farmers in Burkina Faso both for a first and second generation GM crop. In Burkina Faso, Bt Cotton, a first generation GM crop has been commercially cultivated between 2009-2017 while African Biofortified Sorghum, a second generation crop is in the field trial stage. Because the same farmers are considered, we can get insight in the differences in attitude of farmers towards these two types of biotechnology innovations.

When looking at the results of the conditional logit from the cotton CE (table 3.5) all the attributes were significant determinants of the preferences of farmers. Cotton farmers prefer higher yields, and dislike varieties requiring more insecticide treatments or being more expensive. They also prefer public-private development of seeds above a pure private development. The attribute related to the agricultural practices and that for public seed development were not significant. It is also interesting to see that 51% of the farmers prefer the status quo. In this light it is interesting to note that this holds most for the part of the sample cultivating Bt cotton. This confirms earlier studies that found that farmers are quite satisfied with the advantages of Bt cotton.

In the conditional logit model for sorghum (table 4.6) all attributes are significant. Again farmers, as expected, prefer higher yields and lower prices. Also, the negative attitude towards pure private crop development is confirmed and even a positive attitude towards public development is found. In addition farmers positively evaluate the addition of micro-nutrients to the sorghum varieties, which is of course crucial for the ABS project. Finally, the model output confirms that farmers prefer short maturing varieties. A point which is surprising is that farmers seem to be quite keen on changing their variety for a new one (with only 27 % opting for the status quo).

To be able to interpret and compare the results of both choice experiments better, the WTP for attribute changes was calculated and expressed in terms of % of the status quo price in table 3.7 for cotton and table 4.8 for sorghum. It is interesting to see that the WTP in % of current price for extra yield is clearly lower for cotton than for sorghum. A reason for this might be that sorghum is a food crop and a subsistence crop in the farming systems in Burkina Faso.

For the change from private to public/private partnership seed development, farmers are prepared to pay respectively 12% of the Bt cotton price or 21 % of the sorghum price.

While a reduction in insecticide treatments is clearly valued by the farmers, the WTP for eliminating one treatment is not that high. This could point to the fact that the current price of Bt might be set too high. For sorghum it is quite striking that farmers would be prepared to pay double the current price for the addition of the micronutrients. This is an important finding for the ABS project.

Results show that farmers have a clear interest in the characteristic of pest resistance and are overall quite satisfied with the current configuration of the Bt cotton crop. Moreover, farmers are very open to the addition of micronutrients to the sorghum. Given that it concerns a subsistence crop they seem to reason mainly as consumers, appreciating the health benefits. Further research should reveal whether such clear positive attitude towards a biotechnology crop, is influenced by the mainly positive experiences with BT cotton. Another interesting finding is that for both crops farmers seem to dislike the fact that the crop is developed and commercialized purely by the private sector. They seem to agree that the role of the public sector is to induce private research and to conduct research that will benefit those neglected by the private sector (Pray and Naseem, 2007). This issue seems to be even more sensitive for a food crop like sorghum. Further research could focus on the preference heterogeneity of the sampled farmers. In addition, it would be interesting to see how the experiences with a commercialized GM crop (Bt cotton in this case) contribute in shaping the preferences of farmers towards newly introduced crops.

6.2.2. Comparing perspectives between countries with different levels of experience on GM crops

In this section, the level of knowledge and the perception between Burkina Faso and Kenya farmers were compared. Thus, from this thesis' findings, it has been clearly revealed that overall selected farmers whether in Burkina Faso or Kenya presented a poor knowledge about the theory behind the core concept of agriculture biotechnology. Similarly, knowledge of farmers was found limited about the implementation of GM technology through the three GM events investigated. Moreover, farmers' awareness about the objectives of Bt cotton (Burkina Faso) and the Bt maize (Kenya) were badly interpreted or misunderstood. Subsequently, the misunderstanding of the Bt cotton objective negatively impacted farmers practices regarding the respect of the required number of insecticide treatments. Therefore, the study suggests that the experience of Burkina Faso with Bt cotton could serve as a suitable example to improve Kenyan farmers' awareness to the objective of the GM maize event before its commercial release.

Globally, selected farmers presented a positive perception whether considering the development of the first (Bt maize and Bt cotton) and second (biofortified sorghum) generations of GM crop. The lower use of pesticides as well as the health and environmental benefit through the cultivation of an insect-resistant variety (maize or cotton) were positively perceived. Furthermore, the environmental benefit was found to be a significant determinant factor driving the Eastern farmers in Kenya in the adoption of Bt maize variety. Likewise, the increase of micronutrient in sorghum seeds was hotly appreciated due to the awareness of the majority of farmers to the micronutrient deficiency.

6.2.3. Comparing the impact of the socio-demographic and farm characteristics on GM events

Analyzing the outcomes from farmers' perspectives on the three GM events investigated, the socio-demographic and farm related factors were identified as key determinant parameters. For instance, the level of education had a significant impact on farmers' knowledge to the use of Bt cotton in Burkina Faso. Farmers with high level of education were aware about the main objective of Bt cotton. Similarly, the impact of age was underlined in the intention to adopt GM maize in Kenya. In West Kenya older farmers are more likely to adopt a GM variety than younger farmers. Finally, the previous experience with Bt cotton variety in Burkina appeared to be the determinant factor leading farmers to adopt biofortified sorghum variety in Burkina Faso.

Concerning the farm related characteristics, farm size had a significant effect on farmers' perception on the economic benefit of Bt cotton in Burkina Faso. If the study showed that medium and large farmers groups were quite satisfied, small-scale farmers presented an overall skepticism about the economic benefit. Similar differences were reported when comparing farmers' willingness to pay (WTP) for non-seed cost attributes with GM cotton varieties. The small farmer group presented the highest WTP for improving their cotton yield.

Another farm related factor identified was the stem borer species faced in maize farms in Kenya. The study yielded that the number of stem borer species faced by farmers is a key factor for future adoption in both regions (East and West).

6.3. Implications and recommendations

Conceptually, this dissertation contributes to the ongoing debate about GM technology uptake in Sub-Saharan Africa. It provides insights from farmers based on the local contexts in Burkina Faso and Kenya. This thesis demonstrated that farmers' voice can be put to use in the public debate and consultation about the development, implementation or regulation of agricultural biotechnology. However, there are certain practical implications and recommendations that need to be considered to better value farmers' attitudes towards GM crops.

6.4.1 Empirical contributions

The findings of this study add to the literature on farmers' voices about agricultural biotechnology implementation in Sub-Saharan African (SSA) farming systems. While the GM technology uptake has been controversial in Africa (Dowd-uribe and Bingen, 2011; Abidoye and Mabaya, 2014), and currently driven by a fierce debate between proponents and opponents

(Mabaya et al., 2015; Okeno et al., 2013), farmers' opinions were rarely accounted for (Hall, 2008). Thus, this thesis dissertation makes a historical contribution to debate about the GM technology development and implementation by examining African farmers' perspectives towards insect-resistant varieties as well as a biofortified crop. It came up with new insights from West (Burkina Faso) and East (Kenya) African farmers, that could help to make future adoption of GM crops more successful. The study demonstrated that farmers could play a key role whether accepting or rejecting the GM varieties if their expectations do not match with the objective of the GM technology. Farmers' decision-making will prove crucial to determine the fate of the technology (Schurman, 2017). These research findings also questioned the theory that younger farmers seem to be more likely to adopt new agricultural technology, as reported in previous studies on GM seed adoption (Todua et al., 2017 ; Chimmiri et al., 2006 ; Fernandez-Cornejo et al., 2005).

Methodologically, this research applied Choice Experiments (CE), focusing on some key attributes of GM crop varieties. To the best of our knowledge, the CE approach was almost non-existent in literature as method used in the context of SSA considering the adoption of GM technology by farmers. The study shows that not only the characteristics of the crops are important for the choice of farmers, but also the institutional aspects. The inclusion of these aspects is perhaps the most innovative part of the application of CE in this study, because it helps to understand farmers' preferences from a multidimensional perspective (Saldias, 2016). The CE outcomes shed some light on the influence of the seed provenance, whether public, private or public-private partnership on farmers' preferences. The GM seed source has been one of the main concerns championed by GM opponents because of their fear for a new form of domination of international biotechnology firms (Bowman, 2015). The CE findings also underlined farmers' preferences taking into account the farm size. The assumption that wealthier farmers are more likely to adopt GM crops in SSA (Azadi et al., 2011), was not confirmed, perhaps owing to the institutional context framing GM crop distribution in our study areas. The main advantage of using CE is that it has the potential to generate rich information for policy-makers (Saldias, 2016), in this particular case on the preferences for GM crop traits (insect-resistance, biofortification).

6.4.2 Recommendations

Firstly, while the experience of Burkina Faso with Bt cotton was perceived as a sustainable agricultural model, crucial knowledge gaps in terms of farmers' understanding about pest management and compliance with the refuge strategy were identified. Hence, this extends to the general role of the government to create public awareness about biotechnology. Furthermore, the study suggests adoption of a new multidisciplinary assessment approach will be required, taking into account parameters such as famers' behavior.

Secondly, analyzing farmers’ preferences for the characteristics of GM varieties, whether the first (Bt cotton) or the second generation (biofortified sorghum), the study suggests that pure private seed providers were badly perceived. In this perspective, we recommend a stronger government involvement in the development of new products (public or public-private partnership). The role of the government should be among other things to create awareness, as well as participate in the eventual distribution of the transgenic seeds.

Thirdly, building upon the findings of this study towards the Bt maize development in Kenya, two main recommendations were formulated in the light of policy and future research.

The reinforcement of the communication channels about GM technology, and its objective in particular, tailored towards farmers, as previously advocated by Guehlstorf (2008) as a way to improve farmers’ awareness, and to avoid the misuse of GM seeds.

The re-mapping of the distribution of stem borer species and other damaging insects (such army worm) in order to deploy the most needed GM varieties, in line with farmers’ expectations. The upsurge of army worm insects in Western Kenya, for instance, sparked the need of a re-assessment of pest dynamics in maize production, which seems to be reinforced by the global warming (Netherer and Schopf, 2010).

6.4. Limitation of the study and future research

Like all research undertakings, this dissertation was based on a specific research context. The study poses some limitations that deserve to be acknowledged. Highlighting these limitations also provide opportunities for future research.

The first limitation from this study refers to the number of traits of GM crops investigated. Even though the study considered the implementation of GM technology on food (maize and sorghum) and non-food (cotton) crops, other GM traits such drought tolerance (DT), stacked insect resistant (IR)/DT, virus resistance, etc. could be used to extend farmers’ perspectives on GM crops. For this purpose, a future research taking into account other GM traits will be useful.

From the second limitation, the sample size could be identified in the assessment of farmers’ preferences towards biofortified sorghum. The use of the Choice Experiment (CE) data could be limited for other analysis owing to the small size of farmers interviewed. Similar to the sample size, the number of farmers surveyed in the case study of Kenya was insufficient to come up with an prediction model. Moreover, the study only focused on East and West regions. Given that a regional impact was demonstrated as the key determinant for future adoption of Bt maize in Kenya, the consideration of the other four regions in future research would be interesting to see whether or not others factors could be identified as determinant parameter.

Finally, the limitation related to the GM cotton study could be linked to the limitation of the statistical analysis performed. The study did not consider the heterogeneity impact which could be conducted to group farmers according to their specific preferences.

Appendices

Appendix A1. Original survey questionnaire for cotton producers

Fiche d'enquêtes socio-économiques au Burkina Faso (2015/2016)

« ***Connaissance, attitudes et Préférences des producteurs vis-à-vis de la Biotechnologie dans le système agricole burkinabé : Cas du coton transgénique Bollgard II (Coton Bt)*** »

Zone : …………………………… Nom du Producteur : …………………………………

GPC/Position : …………… Type de Coton : …………… Année Exp. :……………

Village: ………………………… Age: ………… Sexe : ………(0=Femme; 1=Homme)

Superficie totale : ………….ha superficie coton:………….ha

Options de réponses :

1 : Pas du tout d'accord **2 : Pas d'accord** **3 : Partiellement en désaccord**
4 : Partiellement d'accord **5 : D'accord** **6 : Tout à fait d'accord**
7 : Aucune idée **8 : Neutre** (ne préfère pas se prononcer)

1. **Sampling design**

Sample: 324 Farmers in 3 Districts (Bobo, Dedougou and Koudougou)

Pairwise comparison regarding :

- Bt cotton farmers (162) and Non Bt farmers (162) = 324 farmers
- Type of farmers: Small (108), Medium (108) and Large (108) = 324 farmers

2. **Overviews of the questionnaires**

a- Farmers knowledge about Bt Technology (10statements)
(Yes/No)

b- How farmers perceive both varieties (Bt or non Bt) in term of agricultural practices (15 statements)
(True/False/Don't know)

c- Farmers opinion about Bt technology advantages (7 statements)
(7 points Likert scale: 1:Strongly disagree……….4: Neutral………..7: Strongly agree)

d- Health benefit and environmental protection (5 statements)
(True/False/Don't know)

e- Farmers opinion about Bt seed cost (3 statements)
(Yes/No)

f- Number of sprays (1 statement)

g- Decision to forsake Bt cotton (1 statement)
(3 points Likert scale: Agree/Neutre/Disagree)

Questions	Réponse
I- Connaissance des producteurs sur le concept de la « biotechnologie » et le coton transgénique Bollgard II **1.a Concept de la « biotechnologie »** Question 1 : Avez-vous déjà entendu parler du concept « Biotechnologie » ?	
Question 2 : Savez- vous que la biotechnologie est un produit de la biologie moléculaire, basée sur la manipulation des gènes permettant par moment d'ajouter des micronutriments dans les variétés initiales ?	
Question 3 : le coton Bt est un produit biotechnologique	
Question 4 : Avez-vous déjà entendu parler d'autres variétés biotechnologiques autre que le coton Bt ?	
1.b Technologie « Bt » Question 5 : le coton transgénique est issu de l'introgression du *Bacillus thuringiensis* (*Bt*) suite à un croisement entre la variété locale (FK37) et la variété américaine (DP50)	
Question 6 : Savez-vous le *Bacillus thuringiensis* (*Bt*) est une bactérie dont le gène permet à la plante de s'auto-défendre naturellement contre les ravageurs cibles (lépidoptères) grâce à sa toxine dégagée au stade de Préfloraison-Floraison?	
Question 7 : Avec le coton Bt, il n'y a que deux (2) traitements phytosanitaires destinés à contrôler les insectes piqueur-succeurs	
Question 8 : Avez-vous suivi une formation et/ou des essais démonstratifs pour la culture du Bollgard II ?	
II- Opinions des producteurs sur l'efficacité de la « technologie Bt » **2.a Exigence de la production et du travail** Question 9 : En terme de dosage, la production du coton Bt exige les mêmes quantités en fumures organiques et minérales requise par la recherche	
Question 10 : La culture du coton Bt n'affecte aucunement mes pratiques culturales (labour, semis, sarclage, buttage, etc…) en terme de production	
Question 11 : Ma main d'œuvre familiale et/ou extérieurs reste inchangée dans la production du coton Bt	
Question 12 : En cultivant le coton Bt, ma quantité d'insecticides à l'hectare est réduit au 2/3 (2 traitements au lieu de 6)	
Question 13 : hors mis la réduction du nombre de traitement, la culture du coton Bt pressente les mêmes exigences que le coton conventionnel	

2.b Comportement de la plante Question 14 : Le taux de germination des semence Bt ne présente pas de différence particulière comparativement aux semences du conventionnel	
Question 15 : Le taux de « shedding » (verse des capsules) a considérablement diminue depuis que je produis le coton Bt	
Question 16 : Grace à sa résistance naturelle aux chenilles, la plante Bt porte plus de capsule comparativement aux conventionnels	
Question 17 : Le cycle de production du coton Bt reste le même que celui du coton Conventionnel	
2.c Contrôle des ravageurs (traitements phytosanitaires) Question 18 : Depuis que je cultive le coton Bt, les attaques des chenilles ont quasiment disparu ?	
Question 19 : Jamais je n'ai eu recours à un/deux traitement(s) insecticides contre les chenilles depuis que je cultive le coton Bt	
Question 20 : La variété transgénique que je produis résiste très bien aux attaques des lépidoptères	
2.d Temps de travail Question 21 : Avec le coton Bt, j'économise plus en temps de travail avec la réduction du nombre de traitement	
Question 22 : L'entretien de mon champ est plus facile dans la production du coton Bt	
Question 23 : Avec le coton Bt, la pénalité du port des appareils de pulvérisation est assez réduite	
III- Opinions des producteurs sur le « Gain » en rendement coton-graine et la rentabilité, engendré par la « technologie Bt » Question 24 : La variété transgénique que je cultive m'a permis d'améliorer mon rendement coton-graine (15 à 20%)	
Question 25 : Avec le coton Bt, mon revenu net a augmenté comparativement à la variété conventionnelle	
Question 26 : Depuis que j'ai commencé la production du coton Bt, j'arrive à subvenir a assez de mes besoins familiaux	
Question 27 : Depuis que j'ai commencé la production du coton Bt, j'arrive à améliorer mon cadre de vie	
Question 28 : le gain engendre par la production du coton Bt m'aide à élargir mes champs de céréales (Maïs, Mil, Sorgho, etc.)	

Question 29 : Depuis que mon GPC produit le coton Bt, nous arrivons à couvrir nos crédits auprès des sociétés cotonnières	
Question 30 : Depuis que je cultive le coton Bt, j'envisage de plus en plus l'élargissement de la superficie de mon champs au fil des campagnes agricoles	
IV- Opinions des producteurs sur la préservation de la santé humaine/animale et des risques environnementaux Question 31 : La réduction du nombre de traitements insecticides préserve ma sante et celle de ma famille	
Question 32 : Grace à ces deux traitements phytosanitaires dans mon champ de coton Bt, les maux après pulvérisations ont considérablement baissé	
Question 33 : Avec moins de quantité d'insecticide utilisée dans la production du Bt, on préserve nos sources d'eau	
Question 34 : Avec le coton Bt, le stock d'insecticides a nettement diminue dans nos magasin et préserve l'environnement aussi	
Question 35 : Mon bétail broute dans mon champ de coton Bt sans être dommage	
Question 36 : Dans mon champ de coton je constate la présence des abeilles au state floraison	
V- Opinions des producteurs sur le cout de la semence Bt Question 37 : Avez-vous une idée sur la fixation du prix de la semence Bt ? (Cout (semence conv+6Traitements insecticides) = Cout (semence Bt+ 2traitements insecticides))	
Question 38 : le prix de la semence (26.000F pour 2015/2016) est abordable	
Question 39 : Avec le cout actuel de la semence, j'arrive à couvrir mes crédit avec les sociétés cotonnières	
VI- Opinions des producteurs sur la décision d'abandonner le coton Bt Question 40 : Avez-vous été informe de la décision de réduire la superficie du coton Bt par les sociétés cotonnières au cours de la campagne 2015/2016?	
Question 41 : Savez-vous ce qui a pousser le gouvernement a suspendre le coton Bt pour la campagne 2016/2017 ?	
Question 42 : L'abandon du coton Bt est dans l'intérêt des producteurs avec les conditions de production actuelle	

Appendix A2. Sample of Discrete Choice Experiment surveys with

Choice Experiment Cotton: Towards small farmers

(inferior or equal to 2ha)

Codification du CE

X1: Rendement (Kg/ha) 1= 675 2= 750 3= 900

X2: Provenance de la technologie 1= publique 2= prive 3= partenariat Publique/prive

X3: Nombre de traitements insecticides 1= 2T 2= 4T 3= 6T

X4: Cout de la semence (Fcfa/ha) 1= 10.000 2= 17.000 3= 25.000 4= 30.000

X5: Pratique Culturale traditionnelles 1= pas de changement 2: changement necessaire

B1-1	**Alternative 1**	**Alternative 2**	**Alternative 3**
Rendement Kg/ha	675	900	750
Provenance de la technologie	Partenariat publique/prive	Prive	Publique
Nbre de traitements insecticides	4T	2T	6T
Cout semence Fcfa/ha	17.000	10.000	25.000
Pratique Culturale traditionnelle	Changement necessaire	Changement necessaire	Pas de changement

A4 : Je prefere maintenir ma facon de produire le coton a l'etat selon les conditions actuelles ………………/……………….

A5 : Aucune des alternatives ne m'interesse J'envisage abandonner la culture du Coton …………../…………….

Laquelle des alternatives ci-dessus presentees preferez-vous? A1/ A2/A3/A4/A5

Choice Experiment Cotton: Towards Medium farmers

(Acreage: Superior to 2ha and inferior or equal to 5ha)

Codification du CE

X1: Rendement (Kg/ha) 1= 900 2= 1.000 3= 1.200

X2: Provenance de la technologie 1= publique 2= prive 3= partenariat Publique/prive

X3: Nombre de traitements insecticides 1= 2T 2= 4T 3= 6T

X4: Cout de la semence (Fcfa/ha) 1= 10.000 2= 17.000 3= 25.000 4= 30.000

X5: Pratique Culturale traditionnelles 1= pas de changement 2: changement necessaire

B1-1	**Alternative 1**	**Alternative 2**	**Alternative 3**
Rendement Kg/ha	900	1.200	1.000
Provenance de la technologie	Partenariat publique/prive	Prive	Publique
Nbre de traitements insecticides	4T	2T	6T
Cout semence Fcfa/ha	17.000	10.000	25.000
Pratique Culturale traditionnelle	Changement necessaire	Changement necessaire	Pas de changement

A4 : Je prefere maintenir ma facon de produire le coton a l'etat selon les conditions actuelles ……………./……………….

A5 : Aucune des alternatives ne m'interesse J'envisage abandonner la culture du Coton …………./…………….

Laquelle des alternatives ci-dessus presentees preferez-vous? A1/ A2/A3/A4/A5

Choice Experiment Cotton: Towards Large farmers

(Superior to 5ha)

Codification du CE

X1: Rendement (Kg/ha) 1= 1.200 2= 1.350 3= 1.600

X2: Provenance de la technologie 1= publique 2= prive 3= partenariat Publique/prive

X3: Nombre de traitements insecticides 1= 2T 2= 4T 3= 6T

X4: Cout de la semence (Fcfa/ha) 1= 10.000 2= 17.000 3= 25.000 4= 30.000

X5: Pratique Culturale traditionnelles 1= pas de changement 2: changement necessaire

B1-1	**Alternative 1**	**Alternative 2**	**Alternative 3**
Rendement Kg/ha	1.200	1.600	1.350
Provenance de la technologie	Partenariat publique/prive	Prive	Publique
Nbre de traitements insecticides	4T	2T	6T
Cout semence Fcfa/ha	17.000	10.000	25.000
Pratique Culturale traditionnelle	Changement necessaire	Changement necessaire	Pas de changement

A4 : Je prefere maintenir ma facon de produire le coton a l'etat selon les conditions actuelles ……………/………………

A5 : Aucune des alternatives ne m'interesse J'envisage abandonner la culture du Coton …………./…………….

Laquelle des alternatives ci-dessus presentees preferez-vous? A1/ A2/A3/A4/A5

Appendix A3. Questionnaire of Biofortified sorghum surveys in Burkina Faso

Connaissances et Perceptions du Producteurs vis-à-vis du Sorgho Bio fortifié

1. Sur les faits

1 : Oui 2 : Non 3 : Sans opinion

Importance du sorgho Je cultive le sorgho pour ma propre consommation			
Ma production de sorgho est uniquement destinée a la vente			
Ma production de sorgho est en partie consommée et transformée en DOLO pour vendre			
Le sorgho constitue notre alimentation principale après le maïs et le mil			
Chaque campagne agricole, je cultive le sorgho			
Origine de la semence Ma semence de sorgho provient de ma production antérieure			
Je paie rarement ma semence de sorgho avec les structures de semences			
L'origine de ma semence importe peu			
Sorgho bio-fortifié et régime alimentaire au Burkina Saviez-vous que les études de la sante publique au Burkina ont révélé l'absence des carences récurrentes en vitamine A, fer et Zinc auprès des enfants de moins de 5 ans et des femmes en ceinte surtout ?			
Saviez-vous que ces carences peuvent être la cause de certains maladies ?			
Vous ou un membres de votre famille a-t-il déjà souffert d'une carence du a l'absence de ces éléments?			
Saviez-vous que ces éléments sont dans le Sorgho et peuvent être améliorés ou enrichis ?			
Avez- vous déjà entendu parle du sorgho bio-fortifie ?			
saviez- vous que le Burkina a souscrit à un programme d'enrichissement du sorgho local pour apporter plus d'éléments comme la vitamine A, le Zinc et le Fer?			

2. Opinions du producteurs

1: Tout à fait d'accord 2: D'accord 3: Sans opinion 4: Pas d'accord

5: Pas du tout d'accord 6: Aucune réponse

Faut-il aller vers le Sorgho bio-fortifie ? Pensez-vous que ce programme de sorgho bio-fortifie est la bienvenue ?						
Pensez-vous que c'est approprié d'améliorer une variété en élément minéral comme le sorgho ?						

Seriez-vous disponible à apprendre plus sur ce programme de sorgho bio-fortifie ?						
Conditions d'adoption ? Je suis régulièrement informe des activités de la recherche sur les variétés améliorées						
Je participe régulièrement aux foires d'exposition des découvertes de la recherche						
Je crois que le sorgho bio-fortifie devrait être mieux explique au producteurs par les structures compétentes						
La semence du sorgho bio-fortifie devrait être disponible au même prix que celle de la variété locale						
Limites probable a l'adoption ? Je préfère continuer avec la variété de sorgho local						
Je produirai le sorgho bio-fortifie à condition que le gouvernement donne son accord						
J'ai une mauvaise expérience avec les variétés présentées comme amélioré						
Je produirai le sorgho bio-fortifie que si le prix est abordable						

Appendix A4. Sample of DCE surveys for sorghum producers in Burkina

Choice Experiment Cards for Sorghum Biofortified (Burkina Faso surveys)

Zone:………………………………………………………… Farmer:…………………………………………………..

B1S1	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
micronutrient added	oui	non	non	oui
Seed cost (Fcfa)	3.000	5.000	4.000	4.000
Crop development	PP	Public	PP	Private
Productivity (yields per ha)	650	850	1.000	750
Days to maturity	110	80	70	95

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

B1S2	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
micronutrient added	oui	oui	non	non
Seed cost	4.000	3.000	5.000	3.000
Crop development	Private	PP	Public	Private
Productivity (yields per ha)	750	850	650	1.000
Days to maturity	110	70	95	80

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

B1S3	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
micronutrient added	oui	non	non	oui
Seed cost	3.000	5.000	4.000	3.000
Crop development	Public	Public	PP	Private
Productivity (yields per ha)	750	850	850	650
Days to maturity	70	110	95	80

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

B1S4	Alternative 1	Alternative 2	Alternative 3	Alternative 4
micronutrient added	non	oui	oui	non
Seed cost	5.000	3.000	4.000	5.000
Crop development	Private	PP	Public	PP
Productivity (yields per ha)	650	850	1000	750
Days to maturity	110	95	70	80

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

B1S5	Alternative 1	Alternative 2	Alternative 3	Alternative 4
micronutrient added	non	oui	oui	non
Seed cost	3.000	5.000	3.000	4.000
Crop development	PP	Public	Private	Public
Productivity (yields per ha)	850	1000	650	750
Days to maturity	110	95	80	70

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

B1S6	Alternative 1	Alternative 2	Alternative 3	Alternative 4
micronutrient added	non	oui	oui	oui
Seed cost	4.000	5.000	3.000	3.000
Crop development	PP	Private	PP	Public
Productivity (yields per ha)	650	750	1000	850
Days to maturity	70	95	110	80

Alternative 5: je préfère ma production actuelle
Alternative 6: j'envisage abandonner la production de sorgho

Appendix A5. Questionnaire toward surveys in Kenya

Questionnaire Sheet Assessing Farmers' Knowledge, Perception, Preferences and Opinions towards GM Maize adoption in Kenya farming systems (Survey of May 2017)

Socio-economic characteristics

Location (Region): ……………………………… Village: …………………………

Name of household head: ………………………………………… Age: …………

Gender: ………(0=Female; 1=Male) Active members in household:………………

Household total acreage: ………….acre Total acreage of Maize:………….acre

Total acreage for other crops: …………..( )……………( )

………….. ( )……………( ) ………………………………………

Level of education: ……

1- Illiterate
2- Primary school
3- Secondary school
4- College
5- university

*Formal agricultural training (*optional*)

Maize seed provenance : ………

1. Farm saved (recycle) seed
2. Commercial seed

Type of variety used: …………

1- Hybrid maize
2- Open Pollinated Variety

Name of the maize variety grown:

……………………………..

Days to maturity: ……….months

Please list the materials of the household used for tillage operations: ………………

1. Plough
2. Tractor
3. Human labor
4. Others: …………………………….

Do you belong to a farmer organization?.................(1=Yes; 2=No)

If yes, name it: ………………………………..

Your position over there: ……

1. head
2. Other official
3. Regular member

How many bags of maize have you get this year? ……………….

How many bags of maize did you sell on the local market? …………………….

How many times you cultivate maize during a year ……………..

1. Constraints and Factors affecting maize production in Kenya farming system

1.1 Water availability and soil fertility are commonly known as natural constraints affecting agricultural production in SSA countries. Except those aforesaid factors, could you please list if known others factors which affect your maize production?

1:………………………… 2:………………………………………….

3:………………………… 4:………………………………………….

1.2 According to your experience in maize production and based on your current agricultural practices, how do the following factors (table below) constraint your current maize production?

Notation to follow 1: No effect; 2: Minor effect; 3: Neutral; 4: Moderate effect; 5: Major effect

NB: It's not about the cost effect but effect such as quality and/or damage caused

Identified factors	**Level of Affect**
Quality of seed (quality of variety grown)	
Farming practices (tillage system and operations)	
Weed control (method used)	
Insect and disease management	
Fertilizers used (quality and mode of application)	
Quality of herbicides and insecticides used	
Harvest storage conditions	

2. Appropriateness to develop an insect-resistant variety

2.1 Insects and diseases are stated by entomologists as major constraints affecting the yield in maize production in SSA.

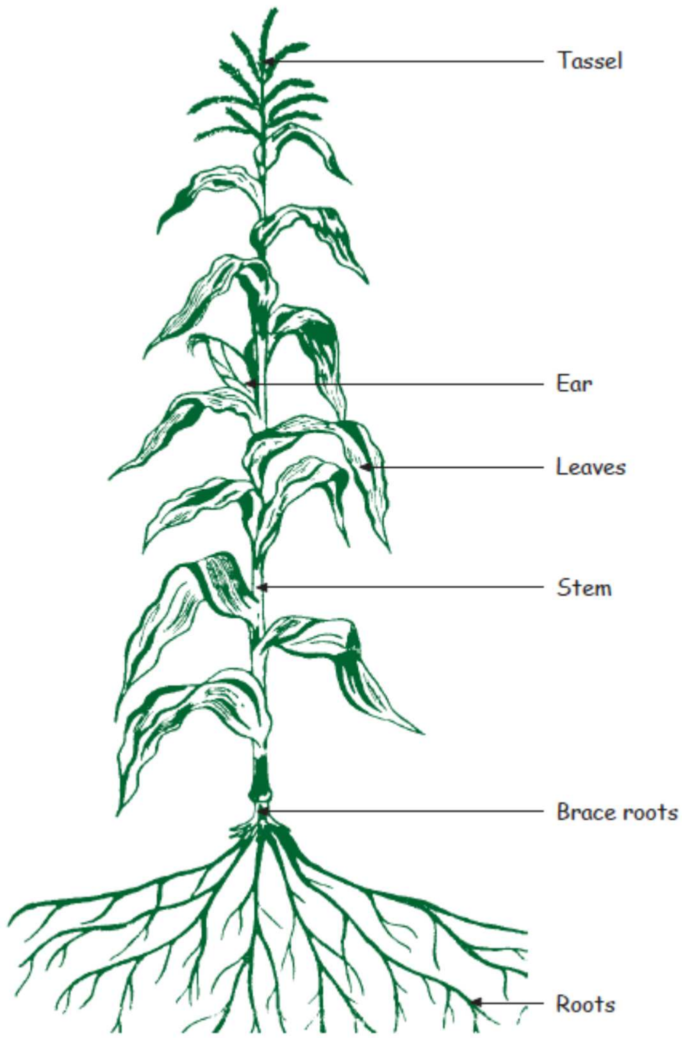
- Do you agree with? ……….(1 = Yes; 2 = No)

- If Yes, could you please list if know insects and/or diseases which usual damage your maize production?

Insects: ……………………………………………………………………………………..

Diseases: …………………………………………………………………………………...

2.2 According to the damage of insects and diseases that you are usually facing in your maize field, could you please state through the figure below which part (s) is (are) commonly attacked? Please use this frequency notation (1 to 5) to value the parts attacked. 1: never; 2 rarely; 3: sometimes; 4: often; 5: always



Insects	**Diseases**
……………………	…………………
Ear = Cob	
………………………	…………………
………………………	…………………
………………………	…………………
…………………………..	…………………
………………………	…………………

2.3 Based on the stages of maize plant growth, could you please indicate how important is the insect and disease damage at each stage of production? Please score from 1 to 5:

1 = not at all important; 2 = of low importance; 3 = neutral; 4 = moderately important;

5 = very important.

Stages of maize production	**Level of insect/disease importance (1 to 5)**
a. From planting to seed emergence	
b. Knee height stage	
c. Silk appearance and pollen shedding	
d. Milk stage	
e. Roosting/boiling stage	
f. Drying of kernels (biological maturity)	

2.3 Stem borers are stated as the main insects damaging maize fields in SSA countries. Among the four insects listed below, could you please give an estimation of the level of problem that you usually face in the control of those insects? Please follow this notation: 1 = not at all a problem; 2 = minor problem; 3 = moderate problem; 4 = serious problem.

i. *Chilo partellus* ……….

ii. *Busseola fusca* ……….

iii. *Eldana saccharina* ……….

iv. *Sesamia calamistis* ……….

3. Knowledge towards biotechnology core concept and GM crop Implementation

3.1 Since 2000 Kenya Research has been testing a new variety called GM maize. GM or Bt maize is an insect-resistant variety and could give power to the maize plant to control itself from some predator attacks.

a. Have you ever heard about this ongoing event? ………..(1 = Yes; 2 = No)

b. If yes, how? ………… (Please select from the following possible ways)

1- Friends 2- Extension officer 3-Newspapers (reading) 4- TV/Radio

5- Others:…………………………………………………

3.2 Could you please select one response among the 3 choices based on the following questions

a. GM maize event which is ongoing in Kenya is developed:…………

1- by Kenya national research only

2- in collaboration with other international organization

3- by a private research center

b- The GM variety is expected to:………

1- control all kind of insects in maize production

2- avoid the loss of post-harvest in maize production

3- control only stem borers

3.3 GM crops are biotechnology products. For instance GM maize is also called *Bacillus Thurengiensis* (Bt) maize. Could you please give your understanding as regards with the following points.

a. Have you ever heard about the concept of biotechnology?......................(1=Yes; 2=No)

If Yes, please explain what you understand?.............. (0- No idea 1-Totally unclear 2- Unclear 3-More or less Clear 4-Clear 5- very clear)

b. Have you ever heard about *Bacillus Thurengiensis* (Bt) ?......................(1=Yes; 2=No)

If Yes, please explain what you understand?.............. (0- No idea 1-Totally unclear 2- Unclear 3-More or less Clear 4-Clear 5- very clear)

c. Do you have any idea about how the GM maize variety is currently testing in Kenya ? ?..............(1=Yes; 2=No)

- If Yes, Explain what you know…………… (0- No idea 1-Totally unclear 2- Unclear 3-More or less Clear 4-Clear 5- very clear)

d. The implementation of a variety such GM maize requires some changes in farmers' behaviors. For instance, it should be followed by an implementation of refuge strategy which will guarantee a success to stem borer control in the long term.

- Have you ever heard about refuge area strategy?......................(1=Yes; 2=No)

- If Yes, please explain what you understand: ……………..(0- No idea 1-Totally unclear 2- Unclear 3-More or less Clear 4-Clear 5- very clear)

4. Perception towards advantages and benefits due to the adoption of a GM crops

Adopting an insect-resistant variety such GM Maize is excepted to the use of less pesticides due to the fact that maize plant itself will control the targeted predators (stem borers). And this adoption will likely affect your maize production. This technology can also be implemented in others crops as stated in some countries. Thus, could you please give your appreciation about how benefit would be this kind of varieties (GM crops) in Kenya farming systems?

1 = totally disagree; 2 = disagree; 3 = partially disagree; 4 = neutral; 5 = partially agree; 6 = agree; 7 = totally agree

Statements	**Level of satisfaction**
4.1 I am confident that adopting a variety which controls stem borers in maize production could be a way to improve my yield.	
4.2 Growing a variety controlling damageable insects will not change anything in my farming practices regarding human labors.	
4.3 I do believe that GM crops in general could provide a positive health impact due to the less use of pesticides.	
4.4 In my understanding, GM crops in general is not appropriated for human use and consumption.	
4.5 The environment (e.g. water sources) is not affected by the quantity of insecticides used in our fields	
4.6 It is important that a variety that requires a lower number of pesticides sprays could allow me to gain working-time for other activities.	
4.7 Insects control is not the main concern for me in my maize field so that varieties with insect resistance are not a priority for me.	
4.8 Adopting an insect resistant variety treated with less insecticides could be healthy for my livestock when fed in fields.	
4.9 The current Integrated Pest Management works well so that we don't need any insect resistant crops.	
4.10 I will be eager to adopt an insect-resistant variety if the research found that testing results are positive for commercial release.	

5. Farmers' awareness to research findings

Please use this notation to fill the cases: **1 = true; 2 = false; 3 = don't know/not sure**

Statements	**Level of Judgement**
5.1 Research towards insects damages pointed out stem borers are the main predators in maize production in Kenya	

5.2 Studies showed that stem borers could occasion the loss of crops variant from 15 to 45% during an agricultural campaign.	
5.3 Towards Integrated Pest Management implementation, studies welled that the current strategy used was not suitable so that pest control still remains a serious problem.	
5.4 First outcomes from GM maize trial testing in Kenya showed that the variety itself controls stem borers well so that yield could be improved up to 30%.	
5.5 Decision makers in Kenya agree that a variety such as GM maize will decrease environmental pollution and will be of benefit for farmers health.	
5.6 Investigations led by some researchers towards the efficiency of pesticides used showed that insects are becoming resistant to the insecticides used.	
5.7 Improving maize productivity is considered by decision makers as a feasible option to satisfy national food demands.	
5.8 Among the stem borers, Kenya research has found five (*C. partellus, B. fusca, S. calamistis, E. sacharrina* and *C. orichalcillielus*) as main predators leading to crop loss in maize fields.	
5.9 Recent studies conducted by assessing farmers' preferences towards hybrid or Open Pollinated Variety demonstrated that farmers have more interest in hybrid maize.	
5.10 To guarantee success to GM technology, the gene of *Bacillus thuringiencis* should be incorporated into hybrid maize seed.	

Please feel free to give some problems (not stated above) affecting your farming practices in general

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

……………………………………………………………………………………………………

References

Abate T, Van Huis A, Ampofo JKO (200). Pest Management Strategies in Traditional Agriculture: An African Perspective. *Annu. Rev. Entomol.*, 2000; vol. 45, no. 1, pp. 631–659.

Adamowicz, W., Boxall, P., Williams, M., & Louviere, J. (1998). Stated Preference Approaches to Measuring Passive Use Values: Choice Experiments versus Contingent Valuation. American Journal of Agricultural Economics 80 (1): 64–75.

Ademola, A.A., Morris, E.J., Murphy, D.J., Phillips, P.W.B., Trigo, E., Kearns, P., Li, Y., Quemada, H., Falck-Zepeda, J., Komen, J. (2018). Rationalizing Governance of Genetically Modified Products in Developing Countries. Nature biotechnology 36 (2): 137–39. doi:10.1038/nbt.4069.

Adenle, A. A., Morris, E. J., & Parayil, G. (2013). Status of development, regulation and adoption of GM agriculture in Africa: Views and positions of stakeholder groups. *Food Policy*, *43*, 159–166. https://doi.org/10.1016/j.foodpol.2013.09.006.

Adenle, A.A. (2014). Stakeholders' Perceptions of GM Technology in West Africa: Assessing the Responses of Policymakers and Scientists in Ghana and Nigeria. J Agric Environ Ethics (2014) 27:241–263. DOI 10.1007/s10806-013-9462-y

Adesina, A. A., & Baidu-Forson, J. (1995). Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics*, *13*(1), 1–9. https://doi.org/10.1016/0169-5150(95)01142-8.

AHBFI. (2007). *A global vision with an African focus to fight poor nutrition with nutrient-rich crops. The Africa Biofortified Sorghum Project. Mid-Term Report December 2007*. Nairobi, Kenya; Johannesburg, South Africa; Washington DC, USA.

Alexander, C., Van Mellor, T. (2005). Determinants of corn rootworm resistant corn adoption in Indiana. AgBioForum, 8(4), 197-204.

Alpizar, F., Carlsson, F., & Martinsson, P. (2001). Using Choice Experiments for Non-Market Valuation. *Economic Issues*, *8*, 83–110.

Andekelile, M., & Leon, M. (2016). Prospects of genetic modified maize crop in Africa. *African Journal of Biotechnology*, *15*(15), 571–579. https://doi.org/10.5897/AJB2015.15098

Areal, F.J., Riesgo, L., Rodrı, E. (2011). Attitudes of European Farmers towards GM Crop Adoption. Plant Biotechnology Journal (2011) 9, pp. 945–957. doi:10.1111/j.1467-7652.2011.00651.x.

Ariga J, Jayne TS, Njukia S (2010). Staple food prices in Kenya. Paper presented at COMESA policy seminar, Maputo, Mozambique 25-26 January, 2010.

Arza V, Goldberg V, Vazquez C. (2013). Argentina: Dissemination of genetically modified cotton and its impact on the profitability of small-scale farmers in the Chaco province. *Cepal Rev.*, 2013; no. 107, pp. 127–143.

Autade, R.H., Jadhav, R.M., Sukhadeo, P., Reddy, P.G. (2016). Farmers Perception , Knowledge and Attitude towards Biotech (GM) Crops at Agrowon AgriExpo - A Survey. IJAEB: 8(3): 753-761.. doi:10.5958/2230-732X.2015.00083.2.

Azadi, H., Adenle, A.A., Ammann, K. (2017). How Do Socio-Political Disputes Concerning GMOs Influence Decision-Making in Developing Countries ? CUUK3244-15, ISBN: 978 1 107 15191 8.

Azadi, H., Ghanian, M., Ghoochani, O. M., Khachak, P. R., Taning, C. N. T., Hajivand, R. Y., & Dogot, T. (2015). Genetically Modified Crops: Towards Agricultural Growth, Agricultural Development or Agricultural Sustainability? *Food Reviews International, 9129*(September), 150211124031008. https://doi.org/10.1080/87559129.2014.994816

Bailey, R., Willoughby, R., Grzywacz, D. (2014). On Trial: Agricultural Biotechnology in Africa. Chatham House: Royal Institute of International Affairs.

Bazuin, S., Azadi, H.,Witlox, F. (2011). Application of GM Crops in Sub-Saharan Africa : Lessons Learned from Green Revolution Biotechnology Advances 29 Elsevier Inc.: 908–12. doi:10.1016/j.biotechadv.2011.07.011.

Bennett R, Ismael Y,Morse S, Shankar B. (2004). Reductions in insecticide use from adoption of Bt cotton in South Africa: Impacts on economic performance and toxic load to the environment. *J. Agric. Sci.*, 2004; vol. 142, no. 6, pp. 665–674,.

Bennett R, Morse S, Ismael Y. (2006). The economic impact of genetically modified cotton on South African smallholders: Yield, profit and health effects. *J. Dev. Stud.*, 2006; vol. 42, no. 4, pp. 662–677.

Bett, C., Ouma, J. K., & De Groote, H. (2010). Perspectives of gatekeepers in the Kenyan food industry towards genetically modified food. Food Policy, 35, 332–340. Trends in Biotechnology 35 (3). Elsevier Ltd: 185–86. doi:10.1016/j.tibtech.2016.12.004.

Birol, E., Asare-marfo, D., Karandikar, B., & Roy, D. (2011). *A Latent Class Approach to*

Investigating Farmer Demand for Biofortified Staple Food Crops in Developing Countries: The Case of High-Iron Pearl Millet in Maharashtra, India. HarvestPlus Working Paper (Vol. 7).

Birol, E., Villalba, E.R., & Smale, M. (2008). Farmer preferencefor milpa diversity and genetically modified maize in Mexico:A latent class approach. Development Economics Environ-ment, 4, 521-540.

Birol, E., Villalba, E. R., & Smale, M. (2007). *Farmer preferences for milpa diversity and genetically modified maize in Mexico: A latent class approach. IFPRI Discussion Paper 00726*. https://doi.org/10.1017/S1355770X08004944

Blancke, S., Grunewald, W. (2017). Suggestions for Communicating about Genetic Engineering Isothermal Ampli Fi Cation Strategies for Detection in Micro Fl Uidic

Black, R., Fava, F., Mattei, N., Robert, V., Seal, S., & Verdier, V. (2010). Case studies on the use of biotechnologies and on biosafety provisions in four African countries. *Journal of Biotechnology*, *156*(4), 370–381. https://doi.org/10.1016/j.jbiotec.2011.06.036

Bonnichsen, O. L. E., & Ladenburg, J. (2015). Reducing Status Quo Bias in Choice Experiments. Nordic Journal of Health Economics, Vol. 3 (2015), No.1, pp 47-67.

Borlaug, N. 2007. Feeding a hungry world. *Science* 318(5849): 359.

Bouis and Saltzman, 2017. Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. Global Food Security, Volume 12, March 2017, Pages 49-58 https://doi.org/10.1016/j.gfs.2017.01.009

Bouis H. E., Hotz C., McClafferty B., Meenakshi J. V., Pfeiffer W.H. (2011). Biofortification: a new tool to reduce micronutrient malnutrition. Food and Nutrition Bulletin 2011; 32 (Supplement 1): 31S±40S.

Bowman, A. (2015). Sovereignty , Risk and Biotechnology : Zambia' s 2002 GM Controversy in Retrospect. Development and Chamge 46 (6): 1369–91. doi:10.1111/dech.12196.

Boxall, P., Adamowicz, W. L. Vic., & Moon, A. (2009). Complexity in Choice Experiments : Choice of the Status Quo Alternative and Implications for Welfare Measurement. no. Vic: 503–19. doi:10.1111/j.1467-8489.2009.00469.x.

Breustedt, G., Muller-Scheeßel, J., & Latacz-Lohmann, U. (2008). Forecasting the Adoption of GM Oilseed Rape : Evidence from a Discrete Choice Experiment in Germany. Journal of Agricultural Economics, Vol. 59, No. 2, 2008, 237–256. doi:10.1111/j.1477-9552.2007.00147.x.

Brookes, G., & Barfoot, P. (2016). Biotechnology in Agriculture and the Food Chain Global Income and Production Impacts of Using GM Crop Technology 1996 – 2014. 5698. doi:10.1080/21645698.2016.1176817.

Brookes, G., Barfoot, P. (2017). Environmental Impacts of Genetically Modified (GM) Crop Use 1996 – 2015 : Impacts on Pesticide Use and Carbon Emissions. GM Crops & Food, 8:117–147. doi:10.1080/21645698.2017.1309490.

Carro-ripalda, M., & Astier, S. (2014). Silenced Voices , Vital Arguments : Smallholder Farmers in the Mexican GM Maize Controversy. Agric Hum Values, 31:655–663. doi:10.1007/s10460-014-9533-3.

Carson, R. T., Louviere, J. J., Anderson, D. A., Arabie, P., Bunch, D. S., Hencher, D. A., Johnson, R. M., Kuhfeld, W.F., Steinberg, D., Swait, J., Timmermans, H., & Wiley, J. B. (1994). “Experimental Analysis of Choice.” Market. Lett. 5 (4), 351–368.

Caserta R, de Souza AA. (2017.) Genetically Modified Plants: Think Twice before Saying “No”. JSM Genet Genomics 4(1): 1021.

Cassman, K. G., Dobermann, A., Walters, D. T., & Yang, H. (2003). Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 28 (1), 315 – 358.

Catacora‑Vargas, G., Binimelis, R., Myhr, A.I., Wynne, B. (2017). Socio-economic research on genetically modified crops: a study of the literature. Agriculture and Human Values, https://doi.org/10.1007/s10460-017-9842-4

Chataway J. (2005). Introduction: is it possible to create pro-poor agriculture-related biotechnology? Journal of International Development 17: 597–610.

Chartres, C. J., & Noble, A. (2015). Sustainable intensification: overcoming land and water constraints on food production. Food Security, 7 (2), 235 – 245.

Chimmiri, N., Tudor, K.W., Spaulding, D. (2006). An Analysis of McLean County , Illinois Farmers' Perceptions of Genetically Modified Crops. AgBioForum, 9 (3): 152–65.

Chinedu, O., Sanou, E. I. R., Tur-cardona, J., Bartolini, F., Gheysen, G., & Speelman, S. (2018). “Farmers ’ Valuation of Transgenic Biofortified Sorghum for Nutritional Improvement in Burkina Faso : A Latent Class Approach. Food Policy. Elsevier. doi:10.1016/j.foodpol.2018.06.006.

Chong, M. (2005). Perception of the risks and benefits of Bt egg-plant by Indian farmers. Journal Risk Research, 8(7-8), 617-634.

CIRAD. (2016). Fifteen years of participatory sorghum breeding in Burkina Faso : addressing farmers ’ needs through collaboration. Retrieved April 10, 2017, from

da Silva, L. S., Jung, R., Zhao, Z. yo, Glassman, K., Taylor, J., & Taylor, J. R. N. (2011). Effect of suppressing the synthesis of different kafirin sub-classes on grain endosperm texture, protein body structure and protein nutritional quality in improved sorghum lines. *Journal of Cereal Science*, *54*(1), 160–167. https://doi.org/10.1016/j.jcs.2011.04.009.

Darr, D.A., Chern, W.S. (2002). Analysis of genetically modified organism adoption by Ohio grain farmers. Paper presented at the 6th International ICABR Conference on Agricultural Biotechnology: New Avenues for Production, Consumption and Technology Transfer, Ravello, Italy.

de Bekker-Grob, E. W., Donkers, B., Jonker, M. F., & Stolk, E. A. (2015). Sample Size Requirements for Discrete-Choice Experiments in Healthcare: a Practical Guide. *Patient*, *8*(5), 373–384. https://doi.org/10.1007/s40271-015-0118-z.

De Groote, H., Overholt, W.A., Ouma, J.O., Wanyama, J. (2011). Assessing the Potential Economic Impact of Bacillus Thuringiensis (Bt) Maize in Kenya. African Journal of Biotechnology Vol. 10(23), pp. 4741-4751.

De Groote, H., Overholt, W., Ouma, J.O., Mugo, S. (2003). Assessing the Potential Impact of Bt Maize in Kenya Using a GIS Based Model. Paper presented at the International Agricultural Economics Conference, Durban, August 2003.1–19.

De Groote, H., 2002. Maize Yield Losses from Stemborers in Kenya. Insect Sci. Applic. Vol. 22, No. 2, pp. 89-96.

De Steur, H., Blancquaert, D., Lambert, W., Van Der Straeten, D., Gellynck, X. (2014). Conceptual Framework for Ex-Ante Evaluation at the Micro / Macro Level of GM Crops with Health Benefits. Trends in Food Science & Technology 39. Elsevier Ltd: 116–34. doi:10.1016/j.tifs.2014.06.010.

De Steur, H., Demont, M., Gellynck, X., & Stein, A. J. (2017). The social and economic impact of biofortification through genetic modification. *Current Opinion in Biotechnology*, *44*, 161–168. https://doi.org/10.1016/j.copbio.2017.01.012.

Demont, M., Cerovska, M., Daems, W., Mathijs, E., Soukup, J., Tollens, E. (2008). Ex Ante Impact Assessment under Imperfect Information : Biotechnology in New Member States of the EU. Journal of Agricultural Economics 59 (3): 463–86. doi:10.1111/j.1477-9552.2008.00157.x.

Dhar, R., & Itamar, S. (2003). The effect of forced choice on choice. J Market Res 40: 146–160.

Diallo Y. (2018). Identifying Leading Seed Companies in Western and Central Africa: Landscaping study for the Regional Access to Seeds Index for Western & Central Africa. Access To Seeds Foundation. https://www.accesstoseeds.org/app/uploads/2018/05/Leading-Seed-Companies-in-Western-and-Central-Africa.pdf

Dogliotti, S., Giller, K. E., & Van Ittersum, M. K. (2014). Achieving global food security whilst reconciling demands on the environment: report of the First International Conference on Global Food Security. Food Security, 6 (2), 299 – 302.

Doherty, E., Campbell, D., Hynes, S., & Rensburg, T. Van. (2011). The effect of using labelled alternatives in stated choice experiments : an exploration focusing on farmland walking trails in Ireland. *Second International Choice Modelling Conference Annual Conference*, (April).

Dowd-Uribe, B., & Schnurr, M. A. (2016). Briefing Burkina Faso's Reversal on Genetically Modified Cotton. African Affairs, 115/458, 161–172. doi:10.1093/afraf/adv063.

Dowd-Uribe, B. (2014). Geoforum Engineering Yields and Inequality ? How Institutions and Agro-Ecology Shape Bt Cotton Outcomes in Burkina Faso. *Geoforum* 53. Elsevier Ltd: 161–71. doi:10.1016/j.geoforum.2013.02.010.

Dowd-Uribe, B., & Bingen, J. (2011). Debating the Merits of Biotech Crop Adoption in Sub-Saharan Africa : Distributional Impacts , Climatic Variability and Pest Dynamics. 1 *Progress in Development Studies* 11, 1 (2011) pp. 63–68.

Edmeades, S., & Smale, M. (2006). A Trait-Based Model of the Potential Demand for a Genetically Engineered Food Crop in a Developing Economy. Agricultural Economics 35 (2006) 351–361.

European Parliament (EP) resolution June 7 2016: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2016-0247+0+DOC+XML+V0//EN.

Evans, E.A., Ballen, F.H., De Oleo, B., Crane, J.H. (2017). Willingness of South Florida Fruit Growers to Adopt Genetically Modified Papaya: An Ex-ante Evaluation. *AgBioForum, 20(2): 156-162.*

Ezezika, O. C., Daar, A. S., Barber, K., Mabeya, J., Thomas, F., Deadman, J., Wang, D., & Singer, P. A. (2012). Factors Influencing Agbiotech Adoption and Development in Sub-Saharan Africa. *Nature Biotechnology VO - 30* 30 (1): 38. doi:10.1038/nbt0212-193a.

FAO, Food and Agriculture Organization of the United Nations. (2010) The State of Food Insecurity in the World. Report for 2010. Rome

FAO, Food Agriculture Organization of the United Nations. (2009). Food Production Statistics of 2009. FAO/STAT, Rome.

FAO, Food and Agriculture Organization of the United Nations. (2014). Coutry Fact Sheet on Food and Agriculture Policy Trends. Country Situation and Role of Agriculture" 25 (September): 6–9.

FAO, Food and Agriculture Organization of the United Nations. (2017). The State of Food Insecurity in the World. Report for 2017. Rome

FAO, Food and Agriculture Organization of the United Nations. (2015). The State of Food Insecurity in the World. Report for 2015. Rome

FAO, Food and Agriculture Organization of the United Nations. (2000). The State of Food Insecurity in the World. Report for 2000. Rome

Fernandez-Cornejo, J., Chad, H., Ashok, M., 2005. Technology Adoption and Off-Farm Household Income : The Case of Herbicide-Tolerant Soybean. Journal of Agricultural and Applied Economics; Dec 2005; 37, 3: 549-563.

Fernandez-Cornejo, J., McBride, W., 2002. Adoption of bioengineered crops (Agricultural Economics Report No. 810). Washington, DC: US Department of Agriculture Economic Research Service (USDA ERS).

Fiore, A.M., Kim, J. (2007). An integrative framework capturing experiential and utilitarian shopping experience. International Journal of Retail & Distribution Management, Vol. 35 Issue: 6, pp.421-442, https://doi.org/10.1108/09590550710750313

Fischer K, Ekener-Petersen E, Rydhmer L, Björnberg K. Social Impacts of GM Crops in Agriculture: A Systematic Literature Review. (2015). *Sustainability*, 2015; vol. 7, no. 7, pp. 8598–8620.

Fischer, K., Eriksson, C. (2016). Social Science Studies on European and African Agriculture Compared : Bringing Together Different Strands of Academic Debate on GM Crops. Sustainability **2016**, 8, 865 doi:10.3390/su8090865.

Fitt GP. An Australian approach to IPM in cotton: Integrating new technologies to minimise insecticide dependence. *Crop Prot.*, 2000; vol. 19, no. 8–10, pp. 793–800.

Fok, M. (2016). Impacts Du Coton-Bt Sur Les Bilans Fi Nanciers Des Sociétés Cotonnières et Des Paysans Au Burkina Faso. Cah. Agric. 2016, 25, 35001 . doi:10.1051/cagri/2016020.

Frewer, L.J.; Lans, I.A. van der; Fischer, A.R.H.; Reinders, M.J.; Menozzi, D.; Zhang XiaoYong, Xiaoyong; Berg, I. van den; Zimmermann, K.L. (2013). Public perceptions of agri-food applications of genetic modification - a systematic review and meta-analysis. Trends in Food Science and Technology 30 (2013)2. p. 142 - 152.

Garcia-Yi, J., Lapikanonth, T., Vionita, H., Vu, H., Yang, S., Zhong, Y., … Wesseler, J. (2014). What are the socio-economic impacts of genetically modified crops worldwide? A systematic map protocol. *Environmental Evidence*, *3*(1), 24. https://doi.org/10.1186/2047-2382-3-24

Gelaw, F., Speelman, S., & Van Huylenbroeck, G. (2016). Farmers ' Marketing Preferences in Local Coffee Markets : Evidence from a Choice Experiment in Ethiopia. Food Policy 61. Elsevier Ltd: 92–102. doi:10.1016/j.foodpol.2016.02.006.

Glass, S., Fanzo, J. (2017). ScienceDirect Genetic Modification Technology for Nutrition and Improving Diets : An Ethical Perspective. Current Opinion in Biotechnology 44. Elsevier Ltd: 46–51. doi:10.1016/j.copbio.2016.11.005.

Gouse, M., Pray, C.E., Schimmelpfennig, D., Kirsten, J. (2006). Three Seasons of Subsistence Insect-Resistant Maize in South Africa : Have Smallholders Benefited ? AgBioForum, 9(1): 15-22.

Gouse, M., Pray, C.E., Kirsten, J., Schimmelpfennig, D. (2005). A GM Subsistence Crop in Africa : The Case of Bt White Maize in South Africa. Int. J. Biotechnology, Vol. 7, Nos. 1/2/3, 2005.

Grabowski, P. P., Kerr, J. M., Haggblade, S., & Kabwe, S. (2016). Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. *Agriculture, Ecosystems and Environment*, *231*, 54–67. https://doi.org/10.1016/j.agee.2016.06.027

Greene, W. H., & Hensher, D. A. (2003). A latent class model for discrete choice analysis: contrasts with mixed logit. *Transportation Research Part B*, *37*(8), 681–698. https://doi.org/10.1016/S0191-2615(02)00046-2

Guehlstorf, N. P. (2008). Understanding the Scope of Farmer Perceptions of Risk : Considering Farmer Opinions on the Use of Genetically Modified (GM) Crops as a Stakeholder Voice in Policy. J Agric Environ Ethics (2008) 21:541–558. doi:10.1007/s10806-008-9116-7.

Gyau, A., Spiller, A., Enneking, U. (2009). Farmer Acceptance of Genetically Modified Seeds in Germany : Results of a Cluster Analysis. International Food and Agribusiness Management Review 12 (4): 63–82.

Halpin C. (2005). Gene stacking in transgenic plants - the challenge for 21st century plant biotechnology. Plant Biotechnol J. 2005; 3: 141-155.

Hanley, N., Mourato, S., & Wright, R. E. (2001). Choice Modelling Approaches : a Superior Alternative for Environmental Valuation ? *Journal of Economic Surveys*, *15*(3), 435–462. https://doi.org/10.1111/1467-6419.00145.

Hassan R. M. (1998). Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya. CAB International, Wallingford, UK/CIMMYT/KARI. 230 pp.

Hema O, Some HN, Traore O, Greenplate J, Abdennadher M (2009) Efficacy of transgenic cotton plant containing the Cry1Ac and Cry2Ab genes of Bacillus thuringiensis against Helicoverpa armigera and Syllepte derogate in cotton cultivation in Burkina Faso. Crop Prot 28:205–214.

Hensher, D. A., Rose, J. M., & Greene, W. H. (2005). *Applied Choice Analysis, A Primer*. *Cambridge University Press*. https://doi.org/10.1007/9781316136232

Henson, R.K., Roberts, J.K. (2006). Use of exploratory factor analysis in published research – Common errors and some comment on improved practice. Educational and Psychological

Measurement, 66 (3) (2006), pp. 393-416

Holst-Jensen A, Bertheau Y, de Loose M, Grohmann L, Hamels S, Hougs L, Morisset D, Pecoraro S, Pla M, Van den Bulcke M, Wulff D. Detecting un-authorized genetically modified organisms (GMOs) and derived materials. Biotechnol Adv 2012;30:1318e35.

Hoyos, D. (2010). The state of the art of environmental valuation with discrete choice experiments. *Ecological Economics*, *69*(8), 1595–1603. https://doi.org/10.1016/j.ecolecon.2010.04.011

Hubbell, B., Marra, M., & Carlson, G. (2002). Estimating the Demand for a New Technology: Bt Cotton and Insecticide Policies. *Amer. J. Agr. Econ*, *5*(4), 118–132.

Hutchinson W.D., Burkness, E.C. Mitchell, P.D. Moon, R.D. Leslie, T.W. Fleischer, S.F. Abrahamson, M. Hamilton, K.L. Steffey, K.L. Gray, M.E. Hellmich, R.L. Kaster, L.V. Hunt, T.E. Wright, R.J. Pecinovsky, K. Rabaey, T.L. Flood, B.R. Raun. E.S. (2010) Area wide suppression of European Corn Borer with Bt maize reaps savings to non-Bt maize growers. Science, 330 (2010), pp. 222-225

IFPRI. (2015). *2015 Nutrition Country Profile: Burkina Faso*. *Global Nutrition Report.*

International Food Policy Research Institute. (2016). *Global Nutrition Report - From promise to Impact: Ending Malnutrition by 2030*. Washington, DC. https://doi.org/10.2499/9780896295841

ISAAA. (2017). Briefs Brief 53 Global Status of Commercialized Biotech / GM Crops in 2017 : Biotech Crop Adoption Surges as Economic Benefits Accumulate in 22 Years. no. 53.

James, C. (2016). ISAAA Briefs Brief 39 Global Status of Commercialized Biotech / GM Crops : 2016. *ISAAA Briefs*, no. Brief 46: 317. doi:10.1017/S0014479706343797.

James C. (2008). ISAAA Briefs brief 39 Global status of Commercialized biotech / GM Crops : 2008. *ISAAA Briefs*, 2009; no. Brief 46, p. 317.

James C. (2014). Brief 49 Global status of Commercialized biotech / GM Crops : 2014. *Int. Serv. Acquis. Agri-biotech Appl.*, 2014; vol. 49, no. 49, p. 11.

James H. S. Jr., Sulemana I. (2014). Case studies on smallholder farmer voice: an introduction to a special symposium Agricultural Human Values (2014) 31:637–641

Johnson, F. R., Lancsar, E., Marshall, D., Kilambi, V., Bs, B. A., Mu, A., Regier, D. A., Bresnahan, B. W., Kanninen, B., &John F P Bridges. (2013). Constructing Experimental Designs for Discrete-Choice Experiments : Report of the ISPOR Conjoint Analysis Experimental Design Good Research Practices Task Force. Value in Health 61. Elsevier Inc. 3-13. doi:10.1016/j.jval.2012.08.2223.

Johnson, W.G., Owen, M.D.K., Kruger, G.R., Young, B.G., Shaw, D.R., Wilson, R.G., Wilcut, J.W. (2018). U . S . Farmer Awareness of Glyphosate-Resistant Weeds and Resistance Management Strategies. Weed Technology 23 (2): 308–12. doi:10.1614/WT-

08-181.1.

Juma, C. (2011). The New Harvest: Agricultural Innovation in Africa; Oxford University Press: Oxford, UK, 2011.

Juma, C. and Serageldin, I. (2007) Freedom to Innovate: Biotechnology in Africa's Development. A Report of the High-Level African Panel on Modern Biotechnology. Africa Union (AU) and the New Partnership for Africa's Development (NEPAD). DS Print Media, Johannesburg

Kaphengst T; El Benni N, Evans C, Finger R, Herbert S, Morse S, Stupak N. (2011) Assessment of the economic performance of GM crops worldwide. *Final report. Berlin: Ecologic Institute*. 2011; pp. 1–149.

Keating, B. A., Carberry, P. S., Bindraban, P. S., Asseng, S., Meinke, H., & Dixon, J. (2010). Eco-efficient agriculture: concepts, challenges, and opportunities. Crop Science, 50 ,S-109 – S-119.

Keelan, C., Thorne, F.S., Flanagan, P., Newman, C., Mullins, E. (2009). Predicted Willingness of Irish Farmers to Adopt GM Technology. AgBioForum, 12(3&4): 394-403.

Khan M, Damalas CA. (2015). Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan," *Crop Prot.*, 2015; vol. 77, pp. 45–51,.

Khan, M.S., Joyia, F.A. (2018). Chapter 19: Biotechnology and GM crops. In Developing Sustainable Agriculture in Pakistan, K336489_C019.indd 355.

Khan, M. S., G. Mustafa, S. Nazir and F. A. Joyia. (2016). Plant molecular biotechnology: Applications of transgenics. In Khan, M.S., Khan, I.A and Barh, D. (Eds.) *Applied Molecular Biotechnology: The Next Generation of Genetic Engineering*. CRC Press Taylor & Francis, USA, pp. 61–89.

Kikulwe, E. M., Wesseler, J., & Falck-Zepeda, J. (2011). Attitudes, perceptions, and trust. Insights from a consumer survey regarding genetically modified banana in Uganda. Appetite, 57(2), 401–413.

Kimenju, S.C., De Groote, H., Bett, C., Wanyama, J. (2011). Farmers , Consumers and Gatekeepers and Their Attitudes towards Biotechnology. African Journal of Biotechnology 10 (23): 4767–76.

Klervi, N.M., Witte, C.L., Burkink, T.J., Grünhagen, M., Wells, G.J. (2007). A Second Generation of Genetically Modified Food American versus French Perspectives. Journal of Food Products Marketing, Vol 13, 2007, Pages 81-100, https://doi.org/10.1300/J038v13n01_06

Klumper, W., Qaim, M. (2014). A Meta-Analysis of the Impacts of Genetically Modified Crops. PLoS ONE 9(11): e111629. doi:10.1371/journal.pone.0111629.

Kondoh, K., Raymond, A. Jussaume Jr. (2005). Contextualizing farmers' attitudes towards genetically modified crops. Agriculture and Human Values (2006) 23:341–352, DOI 10.1007/s10460-006-9004-6

Kondoh, K., & Jussaume-Jr., R.A. (2006). Contextualizing farm-ers' attitudes towards genetically modified crops. Agricultureand Human Values, 23(3), 341-352.

Kolady, D. E., & Lesser, W. (2006). Who Adopts What Kind of Technologies ? The Case of Bt Eggplant in India. *AgBioForum* 9 (2): 94–103.

Kotey, D. A., Assefa, Y., Van den Berg, J. (2017). Enhancing Smallholder Farmers' Awareness of GM Maize Technology , Management Practices and Compliance to Stewardship Requirements in the Eastern Cape Province of South Africa: The Role of Public Extension and Advisory Services. S. Afr. J. Agric. Ext., Vol. 45, No. 2, 2017: 49 - 63. doi:10.17159/2413-3221/2017/v45n2a433.

Krishna, V. V., & Qaim, M. (2007). Estimating the Adoption of Bt Eggplant in India : Who Benefits from Public – Private Partnership ? Food Policy 32. Elsevie. 523–43. doi:10.1016/j.foodpol.2006.11.002.

Kruger M, Van Rensburg JBJ, Van den Berg J. (2012). Transgenic Bt maize: Farmers' perceptions, refuge compliance and reports of stem borer resistance in South Africa. *J. Appl. Entomol.*, 2012; vol. 136, no. 1–2, pp. 38–50,.

Kuhfeld, W. F., Tobias, R. D., Garratt, M., & Kuhfeld, W. F. (1994). Efficient Experimental Design with Marketing Research Applications. Journal of Marketing Research, Vol. 31, No. 4 (Nov., 1994), pp. 545-557.

Lacy, S. M., Cleveland, D. A., & Soleri, D. (2006). Farmer choice of sorghum varieties in southern Mali. *Human Ecology*, *34*(3), 331–353. https://doi.org/10.1007/s10745-006-9021-5

Lancaster, K. (1966). A New Approach to Consumer Theory. *Journal of Political Economy*, *74*(2), 132–157. Retrieved from http://www.jstor.org/stable/1828835

Lancsar, E., & Louviere, J. (2008). Conducting Discrete Choice Experiments to Inform Health Care Decision Making : A User â€™ s Guide , Experiments to Inform Healthcare A User ' s Guide. *PharmacoEconomics*, *26*(December 2015), 661–677. https://doi.org/10.2165/00019053-200826080-00004

Lavidge, R., Steiner, H.E. (1961). A model for predictive measurements of advertising effectiveness. Journal of Marketing 25:59-62.

Lewin, A.C. (2007). Zambia and genetically modified food aid. Cornel University, Ithaca, New York.

Lewis, C.P., Newell, J.N., Herron, C.M., Nawabu, H., 2010. Tanzanian Farmers’ Knowledge and Attitudes to GM Biotechnology and the Potential Use of GM Crops to Provide Improved Levels of Food Security. A Qualitative Study. BMC Public Health 10: 407. doi:10.1186/1471-2458-10-407.

Li, S. L., Zhang, Y. B., Rui, Y. K., & Chen, X. F. (2012). Nutrient content in maize kernels grown on different types of soil. *Phyton*, *81*(2), 41–43.

Lin, C., Pan, T. (2016). Perspectives on genetically modified crops and food detection. Journal of food and drug analysis 2 4 (2 0 1 6) 1-8

Lindsay, M. J., Hanson, K., & McPake, B. (2009). How to do (or not to do)...Designing a discrete choice experiment for application in a low-income country. *Health Policy and Planning*, *24*(2), 151–158. https://doi.org/10.1093/heapol/czn047

Lindsay, M. J., Hanson, K., & McPake, B. (2009). How to Do (or Not to Do) . . . Designing a Discrete Choice Experiment for Application in a Low-Income Country. Health Policy and Planning 2009;24:151–158. doi:10.1093/heapol/czn047 151–58. doi:10.1093/heapol/czn047.

Liu YB, Tabashnik, (1997). Inheritance of resistance to Bacillus thurengiencis toxin Cry1C in the diamondback moth. App Environ Microbiol 2218-2223.

Lokko, Y., Heijde, M., Schebesta, K., Scholtès, P., & Van Montagu, M. (2018). Biotechnology and the Bioeconomy — Towards Inclusive and Sustainable Industrial Development. New Biotechnology. Elsevier B.V.: 5–10. http://dx.doi.org/10.1016/j.nbt.2017.06.005

Louviere, J.J., Pihlens, D., & Carson, R., (2010). “Design of discrete choice experiments: a discussion of issues that matter in future applied research. Journal of Choice Modelling, ISSN 1755-5345, Institute for Transport Studies, University of Leeds, Leeds, Vol. 4, Iss. 1, pp. 1-8.

Louviere, J. J., Hensher, D. A., & Swait, J. D. (2000). Stated choice methods: analysis and application. *Cambridge University Press*. https://doi.org/10.1002/jae.701

Louviere, J. J., Street, D., Burgess, L., Wasi, N., Islam, T., & Marley, A. A. J. (2008). Modeling the choices of individual decision-makers by combining efficient choice experiment designs with extra preference information. *Journal of Choice Modelling*, *1*(1), 128–164. https://doi.org/10.1016/S1755-5345(13)70025-3

Mabaya, E. (2016). Adoption of GM crops in Africa : why the seed sector matters. *Analyses*.

Mabaya, E., Fulton, J., Simiyu-Wafukho, S., & Nang’ayo, F. (2015). Factors influencing adoption of genetically modified crops in Africa. *Development Southern Africa*, *32*(5), 577–591. https://doi.org/10.1080/0376835X.2015.1044078

Maia, A.G., da Silveira, J.M.J. (2016). How Latent Attitudes Affect Farmers' Preferences for Genetically Modified Seeds: The Case of Small Corn Growers in Brazil. AgBioForum, 19(1): 72-84

Marra, M., Hubbell, B., Carlson, G. (2001). Information quality, technology depreciation, and Bt cotton adoption in the Southeast. Journal of Agricultural and Resource Economics, 26(1), 158-175.

Mathenge, M.K., Smale, M., Olwande, J. (2014). The Impacts of Hybrid Maize Seed on the Welfare of Farming Households in Kenya. Food Policy 44. Elsevier Ltd: 262–71. doi:10.1016/j.foodpol.2013.09.013.

Méda, Y.J.M., Egyir, I.S., Zahonogo, P., Jatoe, J.B.D., & Atewamba, C. (2018) Institutional factors and farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso, International Journal of Agricultural Sustainability, 16:1, 40-53, DOI: 10.1080/14735903.2018.1429523

Menéndez, R. (2007). How Are Insects Responding to Global Warming ? Tijdschrift voor Entomologie 150: 355–365.

Meyerhoff, J., & Liebe, U. (2009). Status Quo Effect in Choice Experiments : Empirical Evidence on Attitudes and Choice Task Complexity Status Quo Effect in Choice Experiments : Empirical Evidence on Attitudes and Choice Task Complexity. Land Economics. August 2009. 85 (3): 515–528.

Midega CAO, Nyang'au IM, Pittchar J, Brikett MA, Pickett JA, Borges M, Khan ZR. (2012) Farmers' perceptions of cotton pests and their management in western Kenya. *Crop Prot.*, 2012; vol. 42, pp. 193–201.

Miller, B. D. D., & Welch, R. M. (2013). Food system strategies for preventing micronutrient malnutrition. *Food Policy*, *42*, 115–128. https://doi.org/10.1016/j.foodpol.2013.06.008.

Mogas, J., Riera, P., & Bennett, J. (2006). A comparison of contingent valuation and choice modelling with second-order interactions. *Journal of Forest Economics*, *12*(1), 5–30. https://doi.org/10.1016/j.jfe.2005.11.001

Morris E.J. and Thomson J.A. (2014) Genetically modified crops commercialized in South Africa. In *Biotechnology in Africa* (Edited by F. Wambugu and D. Kamanga). Science Policy Reports 7, DOI 10.1007/978-3-319-04001-1_3.

Mugo S, De Groote H, Bergvinson D, Mulaa M, Songa J, Gichuki S (2005). Developing Bt maize for resource-poor farmers – Recent advances in the IRMA project. Afr. J. Biotechnol. 4: 1490-1504.

Mugiira, R.B., Miano, D.W., Assem, S., Wambugu, F., Kiggundu, A., Atokple, I.K., Ochanda, J.O., Sithole-Niang, I., Fagerström, T., Canales, C., Fetene, M., Hailesalassie, T., Lemma, T., Nwuke, K., Sérémé, D., Al Hassan, W.S. (2015). Harnessing Modern Agricultural Biotechnology for Africa's Economic Development, © 2015 Network of African Science Academies (NASAC)

Muhunyu, J.G. (2008). Structural Analysis of Small-Scale Maize Production in the N Akuru District : Challenges Faced in Achieving Stable and High Maize Productivity in Kenya. Journal of Developments in Sustainable Agriculture 3: 74-91.

Mwangi, P.N., Ely, A., 2001. Assessing Risks and Benefits : Bt Maize in Kenya. Biotechnology and Development Monitor, No. 48, p. 6-9.

Nang'ayo, F, Simiyu-Wafukho, S & Oikeh, SO. (2014). Regulatory challenges for GM crops in developing economies: the African experience. Transgenic Research 23(6), 1049–55.

Netherer, S., Schopf, A., 2010. Forest Ecology and Management Potential Effects of Climate Change on Insect Herbivores in European Forests - General Aspects and the Pine Processionary Moth as Specific Example. Forest Ecology and Management 259: 831–38. doi:10.1016/j.foreco.2009.07.034.

Nyinondi, P.S., Dulle, F.W., Nawe, J., 2017. Perception of agricultural biotechnology among farmers, journalists and scientists in Tanzania. University of Dar es Salsam Journals. http://journals.udsm.ac.tz/index.php/lj/article/view/1078/1004

Obi, C. T., Ejiogu, A. O., & Sanou, E. I. R. (2017). The Role of Transgenic Biofortified Food in the Reduction of Hidden Hunger in Nigeria. In *First International Conference of Food Security and Hidden Hunger*. Federal University Ndufu-Aliku, Eboyi State, Nigeria.

Obonyo, D. N., Nfor, L. M., Araya-quesada, M., Farolfi, F., Ripandelli, D., & Craig, W. (2011). Identified Gaps in Biosafety Knowledge and Expertise in Sub-Saharan Africa. *AgBioForum, 14(2): 71-82.*

Odendo, M., Ouma, J., Wachira, W., Wanyama, J., (2003). Economic assessment of maize yield loss due to stem borer in major maize agro-ecological zones of Kenya. Afr. Crop Sci. Conf. Proc. 6, 683-687.

Okeno, J. A., Wolt, J. D., Misra, M. K., & Rodriguez, L. (2013). Africa 's Inevitable Walk to Genetically Modified (GM) Crops : Opportunities and Challenges for Commercialization. *New Biotechnology* 30 (2). Elsevier B.V.: 124–30. doi:10.1016/j.nbt.2012.09.001.

Olembo, K., M'mboyi, F., Kiplagat, S., Sitiney, J., & Oyugi, F. (2010). Sorghum breeding in sub-saharan africa: the success stories. *African Biotechnology Stakeholders Forum*, 37 pages. Retrieved from http://absfafrica.org/downloads/Sorghum Book Series.pdf.

Oparinde, A., Abdoulaye, T., Mignouna, D.B., Bamire, A.S., 2017. Will farmers intend to cultivate Provitamin A genetically modified (GM) cassava in Nigeria? Evidence from a k-means segmentation analysis of beliefs and attitudes. PLoS ONE 12(7): e0179427. https://doi.org/10.1371/journal.pone.0179427

Ortega, D. L., Waldman, K. B., & Richardson, R. B. (2016). Sustainable Intensification and Farmer Preferences for Crop System Attributes : Evidence from Malawi's Central and Southern Regions. World Development Vol. 87, pp. 139–151, 2016 . doi:10.1016/j.worlddev.2016.06.007.

Paiva, C. L., Queiroz, V. A. V., Simeone, M. L. F., Schaffert, R. E., de Oliveira, A. C., & da Silva, C. S. (2017). Mineral content of sorghum genotypes and the influence of water stress. *Food Chemistry*, *214*, 400–405. https://doi.org/10.1016/j.foodchem.2016.07.067.

Pellegrino, E., Bedini, S., Nuti, M., Ercoli, L. (2018). Impact of Genetically Engineered Maize on Agronomic , Environmental and Toxicological Traits : A Meta-Analysis of 21 Years of Field Data. Scientific REPortS (2018) 8:3113. doi:10.1038/s41598-018-21284-2.

Perret C. (2009). Cotton. In Regional Atlas on West Africa, West African studies, L. Brossard (Ed.). Paris, Organization for Economic Co-operation and Develipment, 2009; pp. 191-209.

Pertry, I., Sanou, E. I. R., Speelman, S., & Ingelbrecht, I. (2016). The success story of Bt cotton in Burkina Faso : a role model for sustainable cotton production in other cotton-growing countries ? De Buck et al. Innovative farming and forestry across the emerging world: the role of genetically modified crops and trees. *International Industrial Biotechnology Network (IIBN) e-book*, 2016; pp. 81–93.

Phalan, P., Onial, M., Balmford, A., & Green, R. E. (2011). Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science, 333 (6047), 1289 – 1291.

Poppy, G. M., Jepson, P. C., Pickett, J. A., & Birkett, M. A. (2014). Achieving food and environmental security: new approaches to close the gap. Philosophical Transactions of the Royal Society, B: Biological Sciences, 369 (1639), 20120272.

Pray, C.E., & Naseem, A. (2007). Supplying crop biotechnology to the poor: Opportunities and constraints, The Journal of Development Studies, 43:1, 192-217, DOI:10.1080/00220380601055676

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability, 9 (1), 5-24.

Qaim, M., & Janvry. (2003). Genetically modified crops, corporate pricing strategies, and farmers adoption: The case of Bt cotton in Argentina. American Journal of Agricultural Economics, Vol. 85, (2003) pp. 814–828.

Qaim, M. 2010. The Benefits of Genetically Modified Crops—and the Costs of Inefficient Regulation. *Resources from the Future.*

Qaim M, Kouser S. (2013). Genetically Modified Crops and Food Security. PLoS ONE 8(6):

e64879. https://doi.org/10.1371/journal.pone.0064879

Reddy, M., Vivekanandhan, S. Misra, M., SujataK.Bhatia, S.K., Mohanty, A.K. (2013). Biobased plastics and bionanocomposites: Current status and future opportunities. Progress in Polymer Science38 (2013) 1653–1689, http://dx.doi.org/10.1016/j.progpolymsci.2013.05.006

Renaudin, C., Pelc, H., & Opois, J. (2012). Étude Originale: Cotonnier génétiquement modifié : l'Expérience d'une campagne agricole au Burkina Faso. Cah Agric 21 : 387-94. doi : 10.1684/ agr.2012.0579.

Reynolds, T.W., Waddington, S.R., Anderson, C.L., True, Z., Cullen, A. (2015). Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia Food Sec. 7: 795. https://doi.org/10.1007/s12571-015-0478-1

Ronca, S., Allainguillaume, J., Ford, C.S., Warren, J., Wilkinson, M.J. (2017). GM Risk Assessment : Pollen Carriage from Brassica Napus to B . Rapa Varies Widely between Pollinators. Basic and Applied Ecology 19. Elsevier GmbH: 36–44. doi:10.1016/j.baae.2017.01.007.

Rose, J. M., & Bliemer, M. C. J. (2013). Sample size requirements for stated choice experiments. *Transportation*, *40*(5), 1021–1041. https://doi.org/10.1007/s11116-013-9451-z

Rose, J. M., Bliemer, M. C. J., Hensher, D. A., & Collins, A. T. (2008). Designing efficient stated choice experiments in the presence of reference alternatives. *Transportation Research Part B: Methodological*, *42*(4), 395–406. https://doi.org/10.1016/j.trb.2007.09.002

Ruane, J., & Sonnino, A. (2011). Agricultural Biotechnologies in Developing Countries and Their Possible Contribution to Food Security. *Journal of Biotechnology* 156 (4). Elsevier B.V.: 356–63. doi:10.1016/j.jbiotec.2011.06.013.

Ruel, M.T., Alderman, H., and the Maternal and Child Nutrition Study Group. (2013). Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? www.thelancet.com Published online June 6, 2013 http://dx.doi.org/10.1016/S0140-6736(13)60843

Rungie, C. M., Coote, L. V., & Louviere, J. J. (2011). Structural choice modelling: Theory and applications to combining choice experiments. *Journal of Choice Modelling*, *4*(3), 1–29. https://doi.org/10.1016/S1755-5345(13)70040-X

Saldias, C. (2016). Analyzing the institutional challenges for the agriculture (re)use of wastewater in developing countries. Doctoral Thesis, Ghent University.

Saldias, C., Speelman, S., Drechsel, P., & van Huylenbroeck, G. (2016). A livelihood in a risky environment: Farmers' preferences for irrigation with wastewater in Hyderabad, India. *Royal Swedish Academy of Sciences*, 1–14. https://doi.org/10.1007/s13280-016-0824-3

Saltzman, A., Birol, E., Bouis, H. E., Boy, E., De Moura, F. F., Islam, Y., & Pfeiffer, W. H. (2013). Biofortification: Progress toward a more nourishing future. *Global Food Security*, *2*(1), 9–17. https://doi.org/10.1016/j.gfs.2012.12.003

Sanders, J. (2016). A New Sorghum Production System in Burkina Faso. *Purdue Agriculture*, 1–14.

Sangle, P.M., Satpute, S.B., Khan, F.S., Rode, N.S. (2015). Impact of Climate Change on Insects," Trends in Biosciences 8(14).

Sanchez D. (2015) Genetically modified crops: how attitudes to new technology influence adoption. Report. Securing Australia's Future (SAF) project 05. March, 2015.

Sanou, E.I.R., Gheysen, G., Koulibaly, B., Roelofs, C., Speelman, S. (2018). Farmers ' Knowledge and Opinions towards Bollgard II ® Implementation in Cotton Production in Western Burkina Faso. New Biotechnology 42 (January). Elsevier: 33–41. doi:10.1016/j.nbt.2018.01.005.

Saxena, D., Stotzky, G. (2000). Insecticidal toxin from Bacillus thuringiensis is released from roots of transgenic Bt corn in vitro and in situ. FEMS Microbiology Ecology 33, 35-39.

Scarpa, R., Ferrini, S., & Willis, K. (2005). Performance of Error Component Models for Status-Quo Effects in Choice Experiments. In R. Scarpa and A. Alberini (Eds.), Applications of Simulation Methods in Environmental and Resource Economics. The Economics of non-Market Goods and Resources 6. Dordrecht, Netherlands: Springer.

Schnurr, M.A., Addison, L. (2017). Which Variables Influence Farmer Adoption of Genetically Modified Orphan Crops? Measuring Attitudes and Intentions to Adopt GM Matooke Banana in Uganda. AgBioForum, 20(2): 133-147.

Schnurr, M.A., Mujabi-Mujuzi, S. (2014). No One Asks for a Meal They've Never Eaten.' Or, Do African Farmers Want Genetically Modified Crops? Agric Hum Values (2014) 31:643-648. doi:10.1007/s10460-014-9537-z.

Schreiner, J. A., & Latacz-Lohmann, U. (2015). Farmers ' Valuation of Incentives to Produce Genetically Modified Organism- Free Milk : Insights from a Discrete Choice Experiment in Germany. J. Dairy Sci. 98:7498–7509 http://dx.doi.org/10.3168/jds.2015-9515

Schreiner, J. (2014). Farmers' Valuation of Incentives to Produce GMO-free Milk: A Discrete Choice Experiment. *System Dynamics and Innovation in Food Networks*, *2*, 312–323. https://doi.org/10.1108/bfj.2009.070111haa.001

Schurman, R. (2017). Building an Alliance for Biotechnology in Africa. Journal of Agrarian Change, Vol. 17 No. 3, July 2017, pp. 441– 458. doi: 10.1111/joac.12167

Shiferaw, B., Prasanna, B.M., Hellin, J., Banziger, M., 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Secur. 3, 307-327.

Sinzogan AAC, Van Huis A, Kossou DK, Jiggins J, Vodouhè S. “Farmers’ knowledge and perception of cotton pests and pest control practices in Benin: results of a diagnostic study,” *NJAS - Wageningen J. Life Sci.*, 2004; vol. 52, no. 3–4, pp. 285–303.

Skevas, T., Kikulwe, E.M., Papadopoulou, H., Skevas, I., & Wes-seler, J. (2012). Do European Union farmers reject geneticallymodified maize? Farmer preferences for genetically modifiedMaize in Greece. AgBioForum, 15(3), 242-256.

Slovic, P. (2000). What Does It Mean to Know a Cumulative Risk ? Adolescents' Perceptions of Short-Term and Long-Term Consequences of Smoking. J. Behav. Dec. Making, 13: 259-266 (2000).

Smale, M., Assima, A., Kergna, A., Thériault, V., & Weltzien, E. (2018). Farm family effects of adopting improved and hybrid sorghum seed in the Sudan Savanna of West Africa. *Food Policy*, 74, 162-171.

Smale, M., Byerlee, D., Jayne, T. (2011). Maize revolutions in Sub-Saharan Africa. World Bank, Washington, DC, and Tegemeo Institute, Kenya.

Smyth, S.J., Kerr, W.A., Phillips, P.W.B. (2015). Global Economic , Environmental and Health Benefits from GM Crop Adoption. Global Food Security 7. Elsevier: 24–29. doi:10.1016/j.gfs.2015.10.002.

Solino, M., & Farizo, B. A. (2014). Personal Traits Underlying Environmental Preferences: A Discrete Choice Experiment. PLoS ONE 9(2): e89603. doi:10.1371/journal.pone.0089603.

Stewart, P.A., McLean, W. (2005). Public opinion toward the first, second, and third generations of plant biotechnology. In Vitro Cell. Dev. Biol.—Plant 41:718–724, DOI: 10.1079/IVP2005703

Stone, G.D. (2011). Field versus Farm in Warangal: Bt Cotton, Higher Yields, and Larger Questions. *World Dev.*, 2011; vol. 39, no. 3, pp. 387–398.

Subramanian, A., & Qaim, M. (2010). “The Impact of Bt Cotton on Poor Households in Rural India The Impact of Bt Cotton on Poor Households in Rural India. The Journal of Development Studies 46:2, 295-311. doi:10.1080/00220380903002954.

Subramanian A, M. Qaim M. (2009). Village-wide Effects of Agricultural Biotechnology: The Case of Bt Cotton in India,” *World Dev.*, 2009; vol. 37, no. 1, pp. 256–267.

Sunding, D., Zilberman, D. (2001). The agricultural innovation process: Research and technology adoption in a changing agricultural sector. In B. Gardner & G. Rausser (Eds.), Handbook of agricultural economics, Volume 1. Amsterdam: North Holland Publishing Company.

Taheri, F.; Azadi, H.; D'Haese, M. (2017). A World without Hunger: Organic or GM Crops? *Sustainability* 2017, *9*, 580. DOI: 10.3390/su9040580

Tefera, T., Mugo, S., Mwimali, M., Anani, B., Tende, R., Beyene, Y., Gichuki, S., Oikeh, S.O., Nang'ayo, F., Okeno, J., Njeru, E., Pillay, K., Meisel, B.,Prasanna, B.M., 2016. Resistance of Bt -Maize (MON810) against the Stem Borers Busseola Fusca (Fuller) and Chilo Partellus (Swinhoe) and Its Yield Performance in Kenya. Crop Protection 89. Elsevier Ltd: 202–8. doi:10.1016/j.cropro.2016.07.023.

Tende, R., Mugo, S.N., Nderitu, J.H., Olubayo, F.M., Songa, J.M., Bergvinson, D.J. (2010). "Evaluation of Chilo partellus and Busseola fusca susceptibility to d-endotoxins in Bt maize". Crop Prot. 29, 115-120.

Theriault, V., & Serra, R. (2014). Institutional Environment and Technical Efficiency: A Stochastic Frontier Analysis of Cotton Producers in West Africa. *Journal of Agricultural Economics* 65 (2): 383–405. doi:10.1111/1477-9552.12049.

Thomson J. (2007). Genetically modified crops — good or bad for Africa? Biologist 2007;54(3): 129–33.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, 108 (50), 20260-20264.

Todua, N., Gogitidze, T., Phutkaradze, B. (2017). Georgian Farmers' Attitudes Towards Genetically Modified Crops. Economics World 5 (4): 362–69. doi:10.17265/2328-7144/2017.04.009.

Traore, M., Lompo, F., Thio,B., Ouattara, B., Ouattara, K., Sedogo, M. (2014). Etude des nématodes phytoparasites du sol et des racines sous quatre niveaux de fertilisation minérale en culture de niébé. Int. J. Biol. Chem. Sci. 8(3): 891-902, June 2014. DOI : http://dx.doi.org/10.4314/ijbcs.v8i3.6

Traore, K., & Stroosnijder, L. (2005). Sorghum quality, organic matter amendments, and health: farmers' perception in Burkina Faso, West Africa. *Ecology of Food and Nutrition*, *44*(July 2014), 225–245. https://doi.org/10.1080/03670240590953421

Traoré, D., Héma, O., & Ilboudo, O. (1998). Entomologie et Expérimentation Phytosanitaire. Rapport Annuel Campagne Agricole 1998-1999. Bobo Doulasso, Burkina Faso: Institut de l'Environnement et de Recherches Agricoles (INERA).

Tumusiime, E., Brorsen, W. B., & Vitale, J. D.. (2014). Vertical Integration in West Africa's Cotton Industry: Are Parastatals a Second Best Solution? *Agricultural Economics (United Kingdom)* 45 (S1): 129–43. doi:10.1111/agec.12135.

UNICEF. (2013). *Unicef Humanitarian action for Children - Burkina Faso*. Retrieved from https://www.unicef.org/appeals/files/Burkina_Faso_HAC_2013_28_dec.pdf

Valdivia C, Danda K, Sheikh D, James HS Jr, Gathaara V, Mbure G, et al. (2014) Using translational research to enhance farmers' voice: A case study of the potential introduction of GM cassava in Kenya's coast. *Agriculture and Human Values* 31(4): 673–681.

van Ittersum, M.K., Lenny G. J. van Bussel, J. W., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., Mason-D'Croz, D., Yang, H., van Oort P.A.J., van Loon, M.P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Joachim, H.J., Makoi, R., Ouattara, K., Tesfaye, K. and Kenneth G.C. (2016). Can sub-Saharan Africa feed itself? PNAS December 27, 2016 113 (52) 14964-14969; December 12, 2016 https://doi.org/10.1073/pnas.1610359113

Van Scharrel, A., Van der Sluis, E., 2004. Farm Level Transgenic Crop Adoption Rates in South Dakota. Economics Commentator. Paper 437. http://openprairie.sdstate.edu/econ_comm/437

Van Scharrel, A. (2003). Determinants of South Dakota Farmers' Adoption of Genetically Modified Corn and Soybeans. South Dakota State University, Department of Economics, Master's Thesis, 2003. http://wwwlib.umi.com/cr/sdstate/fullcit?p1415411

Vasil, I.K. (1998). Agriculture: Biotechnology and food security for the 21st century: A real-world perspective. *Nature Biotechnology***volume 16**, pages399–400 (1998). https://doi.org/10.1038/nbt0598-399

Veldwijk, J., Lambooij M. S., de Bekker-Grob, E. W., Smit, H. A., & de Wit, G. A. (2014). The Effect of Including an Opt-Out Option in Discrete Choice Experiments. PLoS ONE 9(11): e111805. doi:10.1371/journal.pone.0111805

Virgin, I., Bhagavan, M., Komen, J., Kullaya, A., Louwaars, N., Morris, E. J., … Persley, G. (2007). *Agricultural Biotechnology and Small-scale Farmers in Eastern and Southern Africa*. *Biotechnology*. Retrieved from http://www.sei-international.org/mediamanager/documents/Publications/Risk-

Vitale, J. D., & Greenplate, J. The Role of Biotechnology in Sustainable Agriculture of the Twenty-First Century: The Commercial Introduction of Bollgard II in Burkina Faso. (2014). Songstad et al. (eds.), Convergence of Food Security, Energy Security and Sustainable Agriculture, Biotechnology in Agriculture and Forestry 67, DOI 10.1007/978-3-642-55262-5_11, © Springer-Verlag Berlin Heidelberg 2014

Vitale, J. D, Ouattarra, M., & Vognan, G. (2011). Enhancing Sustainability of Cotton Production Systems in West Africa: A Summary of Empirical Evidence from Burkina Faso. *Sustainability* 3 (8): 1136–69. doi:10.3390/su3081136.

Vitale, J. D., Vognan, G., Ouattarra, M., & Traore, O. (2010). The Commercial Application of

GMO Crops in Africa: Burkina Faso's Decade of Experience with Bt Cotton. *AgBioForum* 13 (4): 320–32.

Vitale, J. D., Glick, H., Greenplate, J., Abdennadher, M., & Traoré, O. (2008). Second-Generation Bt Cotton Field Trials in Burkina Faso: Analyzing the Potential Benefits to West African Farmers. *Crop Science* 48 (5): 1958–66. doi:10.2135/cropsci2008.01.0024.

Vitale, J. D., Boyer, T., Uaiene, R., & Sanders, J. H. (2007). The Economic Impacts of Introducing Bt Technology in Smallholder Cotton Production Systems of West Africa: A Case Study from Mali. *AgBioForum* 10 (2): 71–84.

Vognan, G., Ouedraogo, O., & Ouedraogo, S. (2002). Description de La Filiere Cotonniere Au Burkina Faso. Rapport Intermediaire. Bobo Dioulasso, Burkina Faso: Institut de L"environnement et de Recherches Agricoles (INERA)," 1–31.

vom Brocke, K., Trouche, G., Weltzien, E., Barro-Kondombo, C. P., Gozé, E., & Chantereau, J. (2010). Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. *Field Crops Research*, *119*(1), 183–194. https://doi.org/10.1016/j.fcr.2010.07.005

Wang, Y., Vitale, J., Park, P., Adams, B., Agesa, B., Korir, M., 2017. Socioeconomic Determinants of Hybrid Maize Adoption in Kenya. Afr. J. Agric. Res. 12 (8): 617–31. doi:10.5897/AJAR2016.11958.

Wield, D., Chataway, J., & Bolo, M. (2010). Issues in the political economy of agricultural biotechnology. Journal of Agrarian Change, 10(3), 342–366.

World Food Programme. (2017). Burkina Faso: Country Brief. Retrieved January 18, 2018, fromhttp://documents.wfp.org/stellent/groups/public/documents/ep/wfp272247.pdf?_ga=1.94460636.1799879439.1481286284

Wu, K. Lu, Y. Feng, H. Jiang, Y. Zhao, J. (2008). Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin-containing cotton. Science, 321 (2008), pp. 1676-1678

Ye, X., S. Al-Babili, A. Kloti, J. Zhang, P. Lucca, P. Beyer and I. Potrykus. 2000. Engineering the provitaminA (β-Carotene) biosynthetic pathway into (Carotenoid-Free) rice endosperm. *Science* 287(5451): 303–305.

Zakaria, H., Adam, H., & Abujaja, A. M. (2014). Knowledge and Perception of Farmers towards Genetically Modified Crops : The Perspective of Farmer Based Organizations in Northern Region of Ghana. *American International Journal of Contemporary Scientific Research Www.americanij.com*, *1 2014*(2 June-July).

Zilberman, D.; Holland, T.G.; Trilnick, I. (2018). Agricultural GMOs—What We Know and Where Scientists Disagree. *Sustainability* 2018, *10*, 1514.

Zhang, Z., Cui, N., Yu, X,. 2017. Predictive Study of Factors Influencing Farmers' Satisfaction with Transgenic Technology Based on Probit Model and Factor Analysis. Revista de la Facultad de Ingeniería U.C.V., 32: 631–43.

Zhang, H., W. Tian, J. Zhao, L. Jin, J. Yang, C. Liu, Y. Yang, S. Wu, K. Wu., J. Cui, Tabashink B.E. and Y. Wu, (2012). Diverse genetic basis of field-evolved resistance to Bt cotton in cotton bollworm from China. (www.pnas.org/cgi/doi/10.1073/pnas.1200156109).

Zongo, B., Diarra, A., Barbier, B., Zorom, M., Yacouba, H., & Dogot, T. (2015). Farmers' Practices and Willingness to Adopt Supplemental Irrigation in Burkina Faso. *International Journal of Food and Agricultural Economics*, *3*(1), 101–117.

Samenvatting

Al sinds het midden van de jaren 1990, wanneer genetisch gemodificeerde gewassen (ggo's) hun intrede deden in de landbouw, zijn ze het onderwerp van een wetenschappelijk maar vooral ook maatschappelijk debat. Gebaseerd op de snelle verspreiding en de gerapporteerde voordelen voor zowel grootschalige als kleinschalige boeren in zowel industrie- als ontwikkelingslanden ziet het merendeel van de wetenschappelijke studies in biotechnologie echter een mogelijke oplossing voor een aantal problemen in ontwikkelingslanden (ondervoeding, voedselzekerheid). Ook internationale organisaties zoals FAO of de Wereldbank delen deze visie.

Niettegenstaande de substantiële agronomische, economische, milieu-, gezondheids- en sociale voordelen voor landbouwers , en ook steeds meer voor de consumenten, die gelinkt worden aan de teelt van ggo's, blijft het een controversieel onderwerp vooral in Europa en Afrika. Terwijl het politieke debat over de adoptie van ggo's volop aan de gang is, is echter het grootste deel van de soja die in Europa wordt geïmporteerd reeds genetisch gemodificeerd. Ook in Afrika waar positieve effecten werden gerapporteerd in de enkele landen die ggo's cultiveerden (Zuid Afrika, Soedan en tot 2016 Burkina Faso), is er omwille van de hevige reacties van tegenstanders weinig vooruitgang in de adoptie.

Wat opvalt in Afrika is dat in het debat omtrent de ontwikkeling, toepassing en regelgeving omtrent ggo's in tegenstelling tot in Europa, de landbouwers nauwelijks betrokken worden. Ook in de literatuur is er nauwelijks aandacht voor de visie van de Afrikaanse landbouwers. Dit doctoraat brengt daar verandering in en focust specifiek op de visie van landbouwers in twee Afrikaanse landen : Burkina Faso en Kenia.

Het onderzoek spitst zich toe zowel op voedselgewassen (sorghum, mais) als op niet-voedselgewassen (katoen) en ook zowel op ggo's van de eerste generatie (Bt-katoen en Bt-maïs) als op de tweede generatie (biofortified sorghum). De onderzoeksvragen focussen op deze drie gewassen. Een eerste objectief was het nagaan van de kennis en begrip en mening van landbouwers in Burkina Faso met betrekking tot de cultivatie van Bt-katoen. Ook de waardering voor verschillende karakteristieken van katoenvariëteiten werd onderzocht. Het tweede objectief was om na te gaan wat de bereidheid is van landbouwers om biofortified sorghum te verbouwen. Het derde objectief tenslotte richtte zich op de intentie van landbouwers in Kenia

om Bt-maïs te verbouwen en welke factoren deze intentie beïnvloeden. Data werd verzameld van 324 landbouwers in Burkina Faso en 150 landbouwers in Kenia.

De resultaten tonen dat de kennis van landbouwers in Burkina Faso met betrekking tot biotechnologie en Bt-katoen ondanks de ruime verspreiding van dit gewas zeer beperkt is en afhangt van hun scholingsniveau en van hun positie binnen de producentengroep. Alhoewel de meerderheid van de landbouwers tevreden zijn over de teelt van Bt-katoen, toont het keuze-experiment aan dat voorkeuren van landbouwers afhangen van de economische voordelen (hogere opbrengst, zaadkosten) maar ook van het vereiste pesticidegebruik. Het onderzoek toont verder aan dat er onvoldoende controle op en kennis van het nodige pestmanagement is. Landbouwers hebben onvoldoende kennis van de vereiste strategieën en passen deze bijgevolg ook niet toe. De beslissing van de overheid van Burkina Faso om de teelt van Bt-katoen te schorsen tenslotte kon op weinig bijval rekenen bij de landbouwers

Inzake het tweede objectief tonen de resultaten dat landbouwers in Burkina Faso zich bewust zijn van het probleem van tekorten aan micronutriënten, maar dat ze zich niet bewust zijn van het concept en de mogelijkheden van biofortificatie. Meer dan 60% van de landbouwers zou echter wel bereid zijn om een genetisch gemodificeerde sorghumvariëteit te verbouwen. Wanneer we tenslotte kijken naar de studie omtrent Bt-maïs in Kenia dan zien we dat slechts 14% van de landbouwers correct op de hoogte is van de resistentie van deze variëteit ten opzichte van ‘stengelboorders’. De intentie om Bt-maïs te gaan verbouwen blijkt af te hangen van zowel het aantal soorten ‘stengelboorders’ die schade berokkenen aan de maïs als van de inschatting van deze schade. Er blijken regionale verschillen in deze factoren te zitten. In West Kenia blijken oudere landbouwers ook meer geneigd te zijn om Bt-maïs te gaan telen, terwijl in het oosten vooral de perceptie omtrent de milieuvoordelen van een verminderd pesticidegebruik de beslissing van de boeren beïnvloedt.

Dit doctoraat is van belang op drie manieren. Het is ten eerste één van de eerste studies die focust op de visie op biotechnologie van landbouwers in Afrika. Ten tweede kan het bijdragen tot de ontwikkeling van betere ggo’s omdat het inzicht geeft in de karakteristieken die Afrikaanse landbouwers belangrijk vinden in de gewassen die ze verbouwen (dit zowel voor voedsel als niet-voedsel gewassen). Tenslotte is de studie ook beleidsrelevant omdat ze problemen met betrekking tot de ontwikkeling en de implementatie van ggo’s in kaart brengt.

Curriculum Vitae

Personal information

Name: Edouard Idrissa Rachid SANOU

Date of birth: May 07th 1986, Burkina Faso

Office address: Department of Agricultural Economics

Ghent University

Coupure Links 653

9000 Ghent, Belgium

Email: iredoouard.sanou@ugent.be

Tel: +32 9 264 5925

Education

April 2015 – to date: Ph. D candidate, Faculty of Bioscience Engineering, Department of Agricultural Economics (Ghent University)

Theme: "Farmers Perspectives on Agricultural Biotechnology: Case Studies of Burkina Faso and Kenya."

July 2011: Ingénieur de Conception, Option: Agronomie (Institut du Développent Rural, Université Polytechnique de Bobo, Burkina Faso) ***Equivalent in English* : Engineering Degree in Rural Development, Option: Agricultural Sciences**

Thème : « Etude des composantes de rendement du cotonnier transgénique dans les agrosystèmes de l'Ouest du Burkina : Cas de Sidéradougou, Gombeledougou et Daboura. »

July 2008: Diplôme d'Etude Universitaire Générale, Option: Science Naturelle (Institut des Sciences de la Vie et de la Nature, Université Polytechnique de Bobo, Burkina Faso). ***Equivalent in English* : Associate Degree, Option: Nature Sciences**

July 2006: Baccalauréat Série D (Candidat libre, Burkina Faso)

July 2005: Baccalauréat Série C (Lycée Ouézzin Coulibaly, Burkina Faso)

Working Experience

April 2015 – July 2018: Ph.D. Researcher, ERAFRIKA Project

Project title: "*Addressing Social Challenges of Biotechnology in Africa. Towards balanced*

Innovation (SocbioAfri)" **(**http://ipbo.vib-ugent.be/projects/erafrica**)**

Research title: "*Integrated Analysis of Relationship between Farming Systems and Socioeconomic Impact and Conditions of Agricultural Biotechnology Applications: Burkina Faso and Kenya*."

August 2012 – August 2014: National Coordinator of Socio-economic studies towards Bt cotton implementation in au Burkina Faso
Framework: Monsanto (Belgium), Oklahoma State University (USA), Cotton companies of Burkina (Sofitex, Socoma, Faso Coton), UNPCB (Union Nationale des Producteurs de Coton du Burkina Faso) and INERA (Institut National de l'Environnement et de la Recherche Agricole)

Objective: "*Assessment of the potential impact of the socio-economic determinants of Bollgard II in Burkina Faso* ".
February 2012 – July 2012: Partial contract at the department of cotton production of SOFITEX (Société des Fibres et Textiles du Burkina Faso). **Position**: Monitoring and Evaluation
July 2010 – December 2011: Internship at the department of the department of cotton production of SOFITEX (Société des Fibres et Textiles du Burkina Faso).

Research Activities

Published papers

1. **Edouard I.R. Sanou**, Godelieve Gheysen, Bazoumana Koulibaly, Caspar Roelofs, Stijn Speelman (2018). "*Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso*". January 2018, *New Biotechnology 42*. DOI:https://doi.org/10.1016/j.nbt.2018.01.005
2. Chinedu Obi , **Edouard I.R. Sanou**, Juan Tur-Cardona, Fabio Bartolini , Godelieve Gheysen, Stijn Speelman (2018). "*Farmers' valuation of transgenic biofortified sorghum for nutritional improvement in Burkina Faso: A latent class approach*". June 2018, *Food Policy*. DOI: https://doi.org/10.1016/j.foodpol.2018.06.006

Book Chapter

1. Pertry I., **Sanou E.I.R.**, Speelman S., Ingelbrecht I. (2016). "*The success story of Bt cotton in Burkina Faso: a role model for sustainable cotton production in other cotton-growing countries?*" In: Innovative farming and forestry across the emerging world: the role of genetically modified crops and trees. Eds. De Buck S., Ingelbrecht I., Heijde M.,

Van Montagu M., IIBN. pp81-93. http://ipbo.vib-ugent.be/wp-content/uploads/2016/12/IIBN-eBook-2016.pdf

Papers under review

1. **Edouard I. R. Sanou**, Juan Tur-Cardona, Jeffrey D. Vitale, Bazoumana Koulibaly, Godelieve Gheysen, Stijn Speelman (2019). "*What kind of biotechnology do farmers prefer? A Discrete Choice Experiment Approach considering Cotton Cultivation in Burkina Faso*". ***In International Journal of Agricultural Sustainability***.
2. **Edouard I. R. Sanou**, Hans De Steur, Dorington O. Ogoyi, Xavier Gellynck, Godelieve, Gheysen, Stijn Speelman (2019). "*Ex-ante Assessment of the Determinants of Farmers'Intention to Adopt Bt Maize in Kenya*". ***In Trend in Biotechnology-Elsevier***.
3. Gheysen G., Maes J., Valcke M., **Sanou E.I.R.**, Speelman S., Heijde M. (2019). "*Acceptance of GM crops in Europe and Africa*". ***in Afrika Focus journal, Ghent University.***

International Conferences

1. International Plant Biotechnology Outreach (IPBO) conference towards Scientific innovation for sustainable development of African Agriculture. 30th – 31st August, 2018, Ghent, Belgium. Abstract accepted for poster exposition: **Edouard I. R. Sanou**, Hans De Steur and Godelieve Gheysen (2018). "*Farmers Mainstreaming in GM crop development : Evidence from Bt maize event in Kenya*."
2. International Association for Plant Biotechnology (IAPB) congress, 19th – 24th August 2018. Dublin, Ireland. Abstract accepted for oral presentation: **Edouard I. R. Sanou**, Dorington O. Ogoyi, Bazoumana Koulibay, Godelieve Gheysen and Stijn Speelman (2018). "*Comparative Assessment of Farmers' Understandings towards adoption of Genetically Modified varieties in Burkina Faso and Kenya*."
3. 30th International Conference of Agricultural Economists (ICAE), June 28th – August 2ndVancouver, Canada. Paper accepted for oral presentation: **Edouard I.R. Sanou**, Juan Tur-Cardona and Stijn Speelman (2018). "*Farmers attitudes towards GMO crops: comparison of attitudes towards first and second generation crops in Burkina Faso*."
4. 6th Annual Biosafety Conference towards Mainstreaming Biosafety in Emerging Biotechnologies for Sustainable Development. 3rd – 6th October, 2017, Nairobi, Kenya.

Abstract accepted for oral presentation: **Edouard I.R. Sanou** and Godelieve Gheysen (2017). "*Farmers' Knowledge and Opinions towards Bollgard II® Implementation in Cotton Production in Western Burkina Faso*."

5. First International Conference of Food Security and Hidden Hunger: Obi Chinedu, Augustine Odinakachukwu and **Edouard I.R. Sanou** (2017). "The Role of Transgenic Biofortified Food in the Reduction of Hidden Hunger in Nigeria". *A paper delivered at the First International Conference of Food Security and Hidden Hunger. Held at Federal University Ndufu-Aliku, Eboyi State, Nigeria on 8th-11 October 2017.*
6. **Sanou E.I.R (2017).** What kind of biotechnology do famers prefer? A Discrete Choice Experiment considering Cotton cultivation in Burkina Faso (BF). Presentation at the BVLE 18th PhD Symposium, Agricultural and Natural Resources Economic, Brussels – April 27, 2017.
7. European Association for the Study of Science and Technology (EASST/4S) Conference: Caspar Roelofs, Sjaak Swart, **Edouard I. R. Sanou** and Menno Gerkema (2016). "Biotechnological innovation and politics in Burkina Faso". Barcelona 2016. August 31- September 3. At: https://www.nomadit.co.uk/easst/easst_4s2016/panels.php5?PanelID=3982

Trainings/Workshops

1. Mainstreaming, Biosafety in Emerging Biotechnologies for Sustainable Development. Nairobi, Kenya: 3rd – 6th October, 2017. Organized by the National Biosafety Authority of Kenya in collaboration with the United States Department of Agriculture (USDA) and African Biosafety Network of Expertise (ABNE).
2. Biosafety in Plant Biotechnology and Risk Assessment. Ghent, Belgium: 16th – 27th October, 2017. Organized by International Plant Biotechnology Outreach (IPBO, http://ipbo.vibugent.be/training/postgraduate-studies).
3. Choice Experiments: Design and Analysis. Leuven, Belgium 26-27 January 2017
4. Specific courses (Doctoral School, UGent):

- Effective Slides, February 2017.
- Introduction to categorical data Analysis with R", March 2017
- Tools for multivariate data Analysis with R", June 2017
- Effective Professional Networking, March 2018
- Project Management, May 2018