Assessment of the impact of Black Coffee Twig Borer, *Xylosandrus compactus* infestation in Ugandan small-scale coffee gardens, and the potential of its suppression through repellence in conjunction with push-pull technology.

Advaith Chakravarthy Shankarkumar

Independent project - 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Biosystems and Technology
Agroecology - Master's Programme
Alnarp 2021

Assessment of the impact of the Black Coffee Twig Borer, *Xylosandrus compactus* infestation in Ugandan small-scale coffee gardens, and the potential of its suppression through repellence in conjunction with push-pull technology.

Advaith Chakravarthy Shankarkumar

Supervisor: Teun Dekker, SLU, Department of Plant Protection Biology
Assistant supervisor: Fred Kabi, Makerere University, Uganda
Examiner: Raj Chongtham, SLU, Department of Plant Protection Biology

Credits: 30 credits
Level: A2E
Course title: Independent Project in Agricultural Science
Course code: 30159
Programme: Agroecology - Master's Programme
Coordinating dept: Department of Biosystems and Technology

Place of publication: Alnarp
Year of publication: 2021
Cover picture: Advaith Chakravarthy Shankarkumar

Keywords: *Coffee - smallholder farmers - livelihoods - BCTB - pest - SplatVerb - Push-pull - repellents - attractant - sustainable pest control*

Swedish University of Agricultural Sciences
Faculty of Landscape Planning, Horticulture and Agricultural Sciences
Department of Biosystems and Technology

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for YES, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for NO, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file.

If you are more than one author you all need to agree on a decision. Read about SLU's publishing agreement here:https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

✅ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.

Acknowledgment

This study was part of the Erasmus+ exchange program between SLU and Makerere University. A big thanks to both institutions for making this study possible. I would also like to thank Erasmus+ for supporting me with funding throughout the entire course of my stay abroad. Also, Impirigiti Rural Training Centre, Iowa State University- Uganda program (ISU-UP), thanks for being a nice host.

There are many people whom I would like to thank for their contributions to this thesis work. First and foremost, my biggest thank you to Dr. Teun Dekker. You have been an ideal supervisor, offering immense support and guidance all throughout the course of this thesis project. I am so grateful to you for having trust in me and offering me the chance to travel and explore the other side of the world. I also thank you for reading through several drafts of this thesis and your valuable comments helped improve the thesis as a whole. I must say, it was a very fruitful experience working with you, as you are a perfect blend of insights and humor. I am looking forward to working with you more.

A big thank you to all the project partners, without whom the project would not have been possible to reach the stage where it is at the moment. I would like to thank individually Dr. Fred Kabi from Makerere University, for being such a nice co-supervisor and the main linking point of the group. I would also like to thank Dr. Godfrey Kagezi and Mrs. Harriet Nakasi for being supportive and sharing your expertise on the natural and social sciences aspects respectively. A very special thanks to Mr. Boby Ogwang, for your kind reception and all the help you provided during my stay in Uganda.

I am grateful to Dr. Gideon Nadiope, National Director of ISU-UP, and all the other members of that team, for the very kind hospitality and for making my stay colorful and memorable. I cannot thank you enough, Mr. Musoviya Lawrence, for the nice company and the immense energy and support you provided during our field works.

A huge thanks to all my family members and friends for the positive energy throughout the course of this study. I am very grateful to my aunt, Dr. Priyadarshini K V R for proofreading, and providing valuable comments which helped improve my thesis on the whole. My parents deserve endless gratitude for their unstinting support and encouragement. Finally, My heartwarming thanks to my grandfather, Mani Thatha, for being my biggest source of energy.

Abstract

Coffee production in Uganda is an important means of income for smallholder farmers and extensively supports rural livelihoods. It contributes to about 20- 30% of the annual export revenue of the country. Yet, coffee production is challenged by many factors. Of these, the black coffee twig borer (BCTB), *Xylosandrus compactus*, is arguably the most important. In this study we conducted semi-structured interviews and online questionnaires of stakeholders: farmers and officials, to assess the perceptions and knowledge levels about BCTB in relation to other coffee-related threats. We also assessed the level of information flow prevailing amongst the stakeholder groups. We did these surveys in the Namasagali sub-county of the Kamuli district. The results show awareness among both groups of this pest and its devastating impacts on coffee production. However, the levels of understanding varied. All the farmers implemented the recommended control measures. They expressed the need for improvements and additional technology since BCTB infestations have been increasing over the years. Control using insecticides were frequently proposed as a way of handling BTCB infestations, even though insecticides are relatively ineffective and would have disastrous impacts on the biodiversity-rich coffee production in agroforestry settings. Therefore, environmentally and economically sustainable alternatives are necessary to avoid the serious transition of the farmers from presently organic methods to adopting unsustainable technologies. We complemented our interview surveys with field trials to test a novel agroecological approach for the management of BCTB based on the "push-pull" principle of cropping systems. This system uses attractants and repellents to divert pests away from the crop. We tested the possibility of using verbenone, an anti-aggregation signal of other bark beetles, for use in integrated BCTB control. We used a wax-based emulsion, SPLAT, for the slow-release of verbenone in the field. We found that a single 2 g dollop of *SplatVerb* per tree reduced BCTB infestations by 60% in small coffee stands. Our results indicate the potential of managing BCTB infestations using push-pull, showing that *SplatVerb* can function as the 'push' component. Future studies should increase the scale of the intervention trials, and test locally available repellents such as aromatic plant extracts. Additionally, test the push-pull concept through combining the repellent with e.g. traps containing attractants. Furthermore, research on mutual expectations and identifying obstacles and possibilities to suggest possible improvements in the stakeholder communication chain to support the dissemination of sustainable innovations to combat BCTB and other threats to coffee production under agroforestry settings.

Keywords

Coffee - smallholder farmers - livelihoods - BCTB - SplatVerb - repellents - attractants - push-pull - sustainable alternatives - perceptions - stakeholders

Table of contents

List Of Figures

(treatment,n=12) compared to untreated trees (control, n=12). The infested twig count in the treatment and control trees did not differ significantly(P-value = 0.337 >0.05) GLMM with binomial distribution was employed.

List Of Tables

Abbreviations

BCTB - Black Coffee Twig Borer

CBB - Coffee Berry Borer

UNHS - Uganda National Household Survey

UCDA - Uganda Coffee Development Authority

ACSA - Advocacy Coalition of Sustainable Agriculture

NaCORI - National Coffee Research Institute

SPLAT - Specialized Pheromone and Lure Application Technology

1. Introduction

1.1 Ugandan agriculture

Agriculture in Uganda remains the major source of livelihood for the people in the country. According to the Uganda Household Survey (UNHS) 2016/17, a majority of Ugandans are engaged in agriculture, forestry, and fishing (65%). Among the three sectors, the agriculture sector accounted for about 36%, making it a core sector in Uganda's economy. Almost 70% of the Ugandan agricultural production is based on smallholder farmers (Shively & Hao. 2012). It comprises a diverse variety of tropical crops that include i) cash crops (coffee, cotton, tea, cocoa, tobacco, and sugarcane), ii) food crops (maize, rice, beans, banana, and other horticultural produce), iii) livestock and iv) fisheries. Amongst these vast varieties of crops grown in the country, coffee is the country's major export commodity, reaching almost 20-30% annual export revenue (UCDA, 2013). As a coffee-producing nation, Uganda ranks 8th largest producer in the world and 2nd in Africa after Ethiopia. More than 85% of the close to 2 million coffee growers in Uganda are smallholder farmers having less than 2.5 ha for production (Kagezi et al. 2019; Wang et al. 2015), and this forms the major source of income as well as employment for this group. The country cultivates two different varieties of coffee – Robusta (*Coffea canephora* Pierre ex Froehn.*)* and Arabica coffee *(Coffea arabica L.)* (Bekele Tesemma. 2008). Robusta coffee is native to Uganda and is widely cultivated in about 80% of the total coffee production area. However, although Robusta coffee yields are 30% higher than for Arabica coffee, the prices are 30% lower because of its inferior taste and flavor (Bekele Tesemma, 2008). Arabica coffee is grown in the more suited high-altitude areas above 1500m above sea level (ASL), while Robusta coffee is grown mostly in the lowland regions of the country covering Central, eastern, mid north, west Nile, and western Uganda that are within 900 – 1500m ASL. This study focuses on this most commonly grown Robusta coffee.

1.2 Coffee production in Uganda

Coffee production in Uganda faces many challenges ranging from abiotic, biotic, and socio-economic factors throughout its production process. As in the rest of Africa, most of the smallholder farmers in the country are largely dependent on rain (Cooper & Coe. 2011) and lack of access to fertilizers (Jayne & Sanchez. 2021) making them dependent on soil conditions. Recent changes in climatic patterns cause many natural constraints such as unfertile soil conditions, drought, excessive rainfall, and flooding (Shively & Hao. 2012; Jassogne et al. 2013; Wagner et al. 2019). These conditions are further exacerbated by the poor management practices by the farmers resulting in reduced and unpredictable yields (Wang et al. 2015). The bigger challenge comes from living organisms such as pests and diseases (Rosenzweig et al. 2001, Anderson et al. 2004), considerably affecting yields (Tenywa et al. 1999; Judith et al. 2018). Additionally, this sector faces several socio-economic challenges as well such as weak purchasing power, high transportation costs, and poor infrastructure affecting market accessibility. Hence, it is of ultimate importance that threats are dealt with urgently to enhance the livelihood and economy of resource-poor farmers.

Generally, coffee production depends on three different factors – the environmental (or climatic conditions), genetic resources (type of variety grown in a region) and management practices (agronomic and post-harvest; Bosselmann et al. 2009). In Uganda, coffee is majorly produced in an agroforestry setting with various food crops and shade trees rather than monoculture stands of

coffee trees. The considerable benefits from this type of cropping systems are well recognized (worldagroforestry.org; Van Noordwijk. 2019). An agroforestry system, as opposed to a more intense, conventional agroecosystem, is less dependent on external inputs such as fertilizers and pesticides and has several environmental and socio-economic advantages. The incorporation of different layers into the ecosystem increases its resilience to the newly emerging pests and diseases and climate changes. Agroforestry improves soil fertility and ecosystem services and reduces erosion and flooding (Milestad et al. 2008). Additionally, this helps in the betterment of farmers' lives as it enhances food security and also economic stability with regular income generation by providing food, firewood, fodder and fruits (Pumariño et al. 2015). Agroforestry systems are particularly well suited for coffee production, as the shade improves quality and yield, and reduces competition of weeds (Bekele Tesemma. 2008). Although shade is good for coffee, there are also some instances where too much shade, particularly during the wet season, can interfere with the quality of production as it becomes prone to fungal infestations. Hence, the management of shade is critical for quality coffee production (Hultman. 2016).

Coffee (*Coffea canephora*) mixed with Banana (*Musa spp.*) is the most common and a traditional agroforestry mixed farming system practiced in Uganda with banana being the primary food crop and coffee the primary cash crop (Oduol & Aluma. 1990). This system is found to occur in most of the fertile regions of the country (Peter. 1990). In addition to coffee-banana agroforestry, there are also other intercrops with coffee such as coffee-maize, coffee-cassava, and coffee-beans. These crops are mainly grown on a subsistence basis for personal consumption and the surpluses are sold to the market for additional revenue. Additionally, there are also shade trees like mango, avocado, barkcloth tree, umbrella tree, and many more that provide products such as fuel, fodder, and timber for household use or as an extra source of income to farmers. Mixed coffee farming also includes animal production and fishing (in areas closer to the rivers) as additional forms of income generation to the local smallholder farmers. Coffee production under agroforestry results in retaining biodiversity leading to lower levels of pest incidence (Karungi et al. 2015; Milligan et al. 2016). However, shaded coffee increases the risk of black coffee twig borer attack, a new invasive beetle species that seriously threatens coffee production in the country. This pest attacks the coffee trees irrespective of the type of system they are grown in and seems to be more prevalent under shaded conditions. Therefore, in order to secure income for smallholder farmers while at the same time preserving the biodiversity-rich agroforestry and the connected ecosystem services, it is pivotal that sustainable interventions are found that can suppress this beetle.

1.3 The Black Coffee Twig Borer (BCTB)

The Black Coffee Twig Borer (hereafter referred to as the BCTB), is a brown to black wood-boring beetle, belonging to the family Scolytidae and insect order Coleoptera, similar to the other pine and spruce bark beetles (Figure 1 a&b). The beetle is native to Southeast Asia (Kagezi et al. 2013), but invasive in many different countries (Rabaglia et al. 2006) except Central and South America (Ngoan et al). The adult male beetles are flightless and spend their entire lifecycle inside the host tree whereas the adult females are winged and can fly 100 m or more (Vanderlaan & Ginzel. 2013) and are the ones responsible for the initiation of new attacks. The females construct a pin-sized tunnel/entry hole into the twigs and deposit a cluster of eggs inside them. The beetle is also known as the 'ambrosia beetle', because of its association with the fungi 'Ambrosia' (Figure1 c). These fungi

are known for their symbiotic association with certain members of Scolytidae beetles and all other Platypolidae (Coleoptera). The BCTB develops by feeding on the fungi cultivated by the females inside the tunnels and acts as the major source of food for the larvae and the adults (Batra. 1963; Gugliuzzo et al. 2020). *Ambrosiella xylebori* and *A. macrospora* are two of the most recurring fungi in symbiotic association with the BCTB, *Xylosandrus compactus* (Gugliuzzo et al. 2020). The fungi are generally associated with the beetle continuously throughout their lifecycle (Batra. 1963). Infection with ambrosia fungus blocks the nutrient flow to the twigs leading to wilting and blackening, which is the final symptom of attack (Batra. 1963; Gugliuzzo et al. 2020). Depending on the size of the twig, infestation by single or several females can be seen and eventually leading to unproductive twigs (Hara & Beardsley. 1979). The BCTB is a polyphagous pest that has been reported to infest more than 224 plant species inclusive of some threatened and endangered species. In Uganda, the first incidence of the BCTB was in 1993 and its severity increased when it spread to different districts in 2011/12 (Kagezi et al. 2013). Even though the pest prefers Robusta coffee, recent studies show that the BCTB attacks Arabica coffee, and 40 other plant species (annual crops and trees) in Uganda (Kagezi et al. 2013; Kagezi. 2017). With its rapid spread to newer Robusta coffee-growing regions, it is of utmost importance to halt this spread, as Robusta accounts for almost 80% of the country's coffee export volume (Musoli et al. 2001).

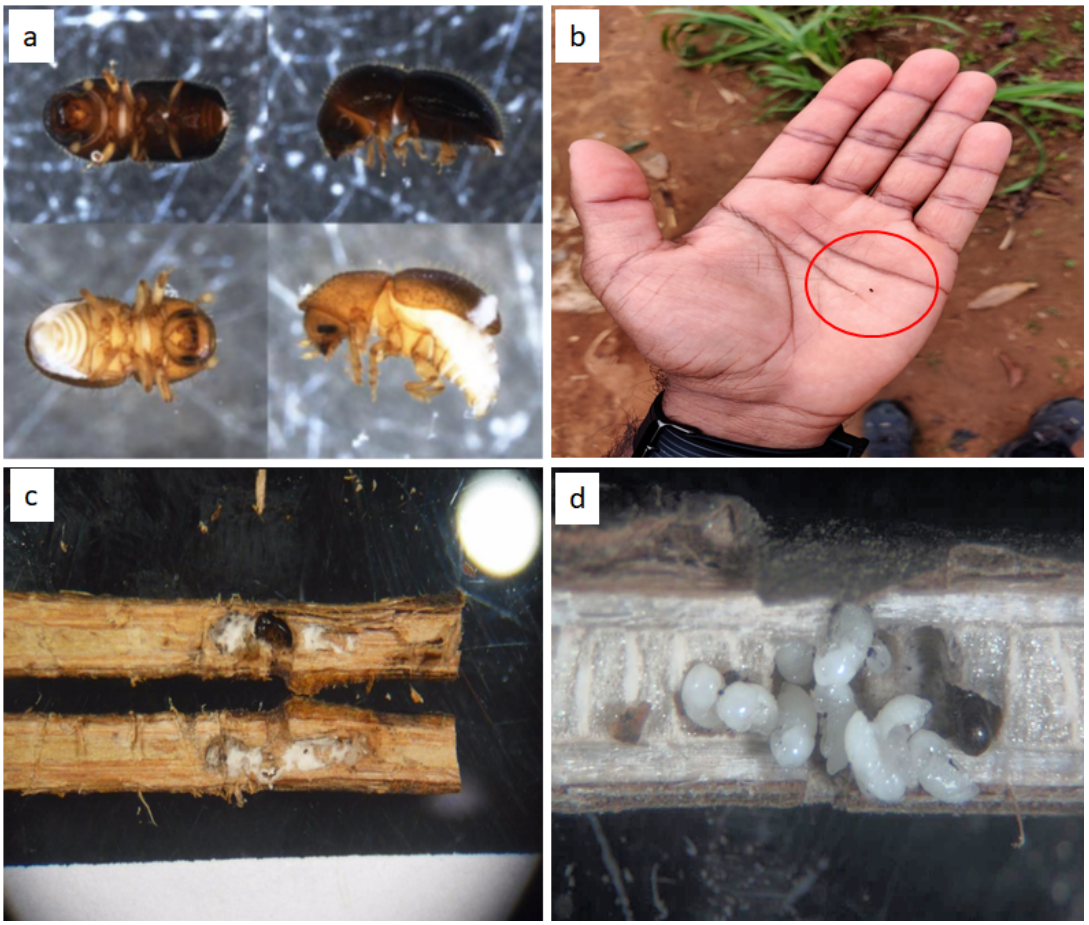

Figure 1: (a) Female BCTB adult on the upper row and male BCTB adult on the bottom row. The photos are not proportional to their real-life size. (Photo: Gerard Malsher, SLU); (b) Real-life size of an adult BCTB; (c) Split up

BCTB infested twig with visible white-colored ambrosia fungus. Also seen is a female tending to its colony (Sourced from imgur.com) ; (d) BCTB pupae clustered inside the twig (Sourced from imgur.com)

In addition to the symbiotic relationship with the ambrosia fungi, an interesting feature of this insect is their haplodiploid nature of reproduction. As a result of this, very few adults can be sufficient to establish a bigger population. Once these beetles are established, they become difficult to control, because these beetles are cryptic most of their life cycle, burrowed inside twigs and out of reach for insecticides. Their small size also makes detection difficult (Reding, Oliver, Schultz, & Ranger, 2010). Hence, conventional insecticide application can only be helpful when applied at the right time before the insect flight period commences with minimal certainty of control (Vanderlaan & Ginzel. 2013). Therefore, better control strategies that are sustainable and well adapted to local conditions and also to farmers are thus needed.

This study stems from one such well-established strategy called the 'Push-Pull technology' (PP) - a behavioral manipulation of insect pests by introducing a component that makes the desired host of the pest undesirable (Push), in this case, the coffee tree, and another component acting as a false host/ trap (Pull) on which the insects fail to survive or will be removed (Cook, Khan, & Pickett. 2007). Originally, PP was adopted in maize-desmodium-napier grass intercropping systems in Africa to control stem borers on maize. In this, the stem borers get repelled from the intercropped desmodium (Push) and tend to move away. These were simultaneously attracted by napier grass on the borders of the field which acted as a dead-end host (Pull) which the insect fed on and died. In this study, I focus on identifying the 'Push' part, which forms a first step toward establishing a push-pull system in Robusta coffee agroforestry. I conducted field trials to explore a novel agroecological technique, where I investigated the repellency of verbenone to the BCTB (Push). Verbenone is an oxidized form of verbenol with a reversed functionality. It functions as an anti-aggregation pheromone whereas verbenol is an aggregation pheromone. Both these compounds are very closely linked to the majority of Scolytidae beetles, but, whether BCTB uses verbenone and verbenol as dispersion and an aggregation compound respectively, is not known. However, verbenone as a potential repellent, can be used in conjunction with, for example, traps (Pull) into a Push-Pull system in other Scolytidae beetles. Earlier studies have used ethanol, as a common attractant for most of the Scolytid beetle species (Miller et al. 1983; Werle et al. 2019). I also integrated attractant traps with verbenone to trap insects, however, the purpose of this has been to estimate local populations of BCTB and not for the purpose of 'pull'. Finally, we also conducted extensive surveys among farmers and agriculture officials to assess perceptions and information flows and to understand the status of BCTB management.

1.4 Project aim

The main aim of this study was to understand the challenges caused by BCTB to coffee farmers in Uganda, and the potential of spatial repellence offered by Verbenone to suppress BCTB populations as a sustainable alternative to farmers.

1.4.1 Project Objectives

The specific objectives were to:

1) Analyse the different perspectives on and management practices to BCTB among the coffee stakeholders' - farmers and officials
2) Assess the stakeholders' perceptions of BCTB in relation to other coffee-related threats
3) Assess the impact of BCTB on coffee production
4) Investigate the influence of verbenone *(SplatVerb)* on the infestation rates of BCTB in single coffee trees small stands - field trial

2. Materials and methods

2.1 Description of the area and farm selection for field trials

This study was entirely conducted in Kamuli district (1°13'45.44"N, 32°53'58.52"E), located in the central-eastern part of Uganda. A reconnaissance survey was performed to over 40+ small-scale coffee gardens to collect the required details such as the size of the fields, age of coffee trees, spacing, management practices, and so on, as well as to better understand the environment. C*offea robusta* was the predominant type grown in the region. The BCTB infestation was found in all the gardens. The farm selection for field trials was based on two factors - the age of trees (2 to 8 years) and the size of the fields (1 ha to 2.5ha). Five different farms were selected based on our survey for the trials. Most of the field trials were conducted in villages - *Kavule, Nansololo*, and *Kikyaichi*, all belonging to Namasagali sub-county (1° 0'36.48"N, 32°57'2.91"E) and one in *Kabukye* village (0°54'26.65"N, 33° 6'42.60"E), all coming under Kamuli district. The fields were at a minimum of 2kms apart. Proper care of the trees was taken in all the chosen fields.

I also carried out face-to-face structured interviews (Wright et al. 1989) with the farmers whose fields were located at different places within the Namasagali sub-county of Kamuli district. All of them were small-scale organic farmers with a diversified coffee production system. The farmers' fields were far apart from one another, but all belonged to the Namasagali sub-county under Kamuli district. In addition, I also conducted online surveys of the officials (Braun et al. 2020) using the online platform 'Google Forms'. The officials were included in the study to evaluate the contrast in the perceptions and also the information flows between officials and farmers. The interview and online survey questionnaires (with questions) are included in the appendix.

2.2 Interviews and surveys

I interviewed a total of 11 farmers, whose contact details were acquired from earlier field visits through other farmers and some of them from the chairman of the sub-county. I randomly selected the farmers to be interviewed. The selected farmers were geographically well distributed across different villages in the sub-county. I also ensured that the chosen farmers were coffee growers and had some knowledge about the BCTB and its symptoms. I began the interviews with a presentation to familiarize the farmers with the topic and to avoid any misunderstandings. The interview sessions

were assisted by a translator as all the interviews were conducted in Lusoga. All the interviews were also recorded with the farmers' permission for future reference. The interview was divided into two parts – general questions and BCTB questions. I framed the questions to focus on specific field-level knowledge and the farmer perceptions about BCTB. Each interview took approximately one hour.

Figure 2. Photos taken during farmer interviews

I also conducted online surveys targeting agriculture officials and scientists working in the same field. Four extension officers from different sub-counties in Kamuli district, one district production officer (DPO) of Kamuli district, one field officer from a public authority (Uganda Coffee Development Authority), three research officers (National Coffee Research Institute), an NGO based in Kamuli district (Impirigiti rural training center, Iowa State University-Uganda Program) were chosen for the online surveys as all of them were working closely with coffee and its management. The surveys were conducted using 'Google Forms'. The online questionnaire was sent to email addresses with prior notice. All the questions were in English. The type of questions for these people differed from the farmers' interview but followed the same structure – general questions and BCTB questions. The questions focused on broader perspectives, village or district level, and not on a field level.

2.3 Verbenone field trial - grouped trees

2.3.1 Plot selection and intervention

After farm selection, I also surveyed the individual farms for setting up the plots for our field trials. I carried out the field trial using the anti-aggregation signal verbenone, which was incorporated into SPLAT (Specialized Pheromone and Lure Application Technology), a base matrix formulation of biologically inert materials (ISCA Technologies, Riverside, CA). SPLAT is a wax-emulsion, which is used for the slow-release of active ingredients such as pheromones and, in this study, verbenone. I set up 8 quadrants (with a group of 9 trees in a square) as treatments and 8 quadrants as control. Each field had 2 paired plots (totaling 4 plots in each field) with a minimum of 20m distance between them. I set these quadrants in 4 different farmer fields and included only healthy trees for our experiment. I marked the boundaries of the quadrants clearly with tape. I inspected all the marked trees and removed all those branches suspected to have BCTB symptoms before SplatVerb use into our treatment quadrants. The dispensers were deployed on the same day as the clearing off. A single dollop of SplatVerb (~2g) was placed on the main stem within the canopy of all the nine treatment

trees in the treatment quadrant. The *SplatVerb* was replenished weekly (once) and for 12 weeks. No application was done for the control trees.

I placed two alcohol traps per quadrant in the treatment quadrants. These were placed in the canopy of the central tree of each plot. These traps comprised bottles of 1.5 L with a small opening for the insects to enter (approximately 8cm length x 6cm height), a 50ml centrifuge tube filled with 30 ml Waragi (locally produced alcohol?) mixed with and a small drop of detergent. The centrifuge tubes were suspended with several holes in it to release the ethanol to attract the beetles. The bottles were hung on each side of the central tree. I made sure to inform the farmers about the experiment so that it was not disturbed throughout the time period.

I monitored the experimental plots weekly for infestation and to track the pest development over the entire course of the experiment. All blackened twigs, as well as twigs with entry holes, were marked with tape to avoid recounting them. SplatVerb and alcohol traps were also replenished weekly. The parameters that we checked are given in Table 1.

Parameters checked during each monitoring
1. Total number of twigs per tree (only the first time) 2. Number of infested trees per plot 3. Total number of infested twigs per tree 4. Number of infested twigs on the Lower & Upper part of the tree 5. Number of entry holes per twig per tree 6. Number of entry holes per twig on the Lower and Upper part of the tree 7. Capture rate of female adults with waragi trap 8. Monitor the natural enemies (Black and red ants)

Table 1. Parameters that were monitored for grouped tree experiment

2.4 Verbenone field trial - single trees

2.4.1 Plot selection and intervention:

I selected two plots after field inspection, one each for treatment and control of size 15m x 15m, which had several coffee trees. Of these, 12 healthy trees were randomly chosen for the trial within each of these plots. The setup and monitoring protocol was exactly the same as of the above-mentioned grouped trees. However, I did not set up alcohol traps for this experiment. The parameters that we monitored for this experiment are given in Table 2.

Parameters
1. Total number of twigs per tree (only the first time) 2. Number of infested trees per plot 3. Number of infested twigs per tree

Table 2. Parameters that were monitored for single tree experiment

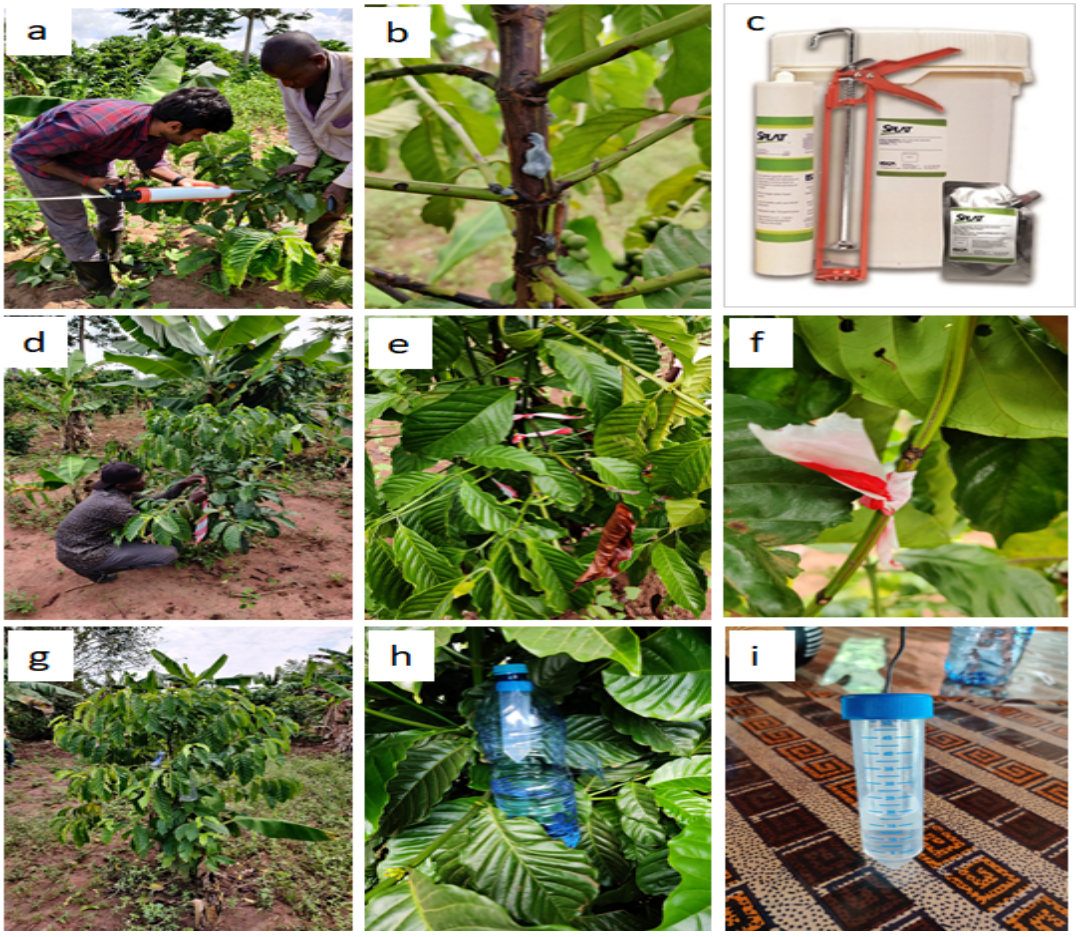

Figure 3. (a) Intervention with *SplatVerb*; (b) *SplatVerb* dollop (~2g) on the main stem; (c) Picture showing *SplatVerb* containers and caulking gun (Source from www.forestrydistributing.com); (d) Field assistant helping with BCTB damage monitoring; (e) BCTB infested twigs marked with tape during monitoring; (f) Entry hole- the first symptom of BCTB; (g) Centre tree with two bottle traps on each side; (h) A closer look on the bottle trap setup; (i) Centrifuge tubes filled with Waragi (30ml).

2.5 Potential loss faced by farmers due to BCTB damage

The damage caused by BCTB is increasing over the years and this is translated directly into seasonal losses in their final harvests. In addition to the social and environmental aspects of coffee production in Uganda, I further assessed the potential yield losses faced by farmers due to BCTB attack, by accessing data acquired from the Advocacy Coalition of Sustainable Agriculture (ACSA). These were only the estimates of loss calculated from the field trial results.

3. Results

3.1 Interviews and online surveys

The interviews and online surveys indicated that coffee was perceived as the most important crop both in terms of the extent of production and economic importance (Figure 4 a & b). Economics was the main motivation for farmers to have coffee as their main cash crop (Figure 5), as coffee supports the livelihoods of smallholder farmers by taking care of the monetary needs of their families such as paying school fees for children, health expenses, expenses for buying tools and equipment and so on. Additionally, we found that in most cases (8 out of 11), coffee cultivation is a family-run enterprise (Figure 6). One of the three farmers who replied 'NO' to a family-run enterprise, is soon expecting coffee to take over other crops as their main source of income. Another farmer responded that he concentrates on other cash crops and not on coffee, since middlemen dealing with coffee marketing are very exploitive. Despite being beneficial to the lives of smallholder farmers, coffee cultivation poses a series of problems to be dealt with before attaining the final income.

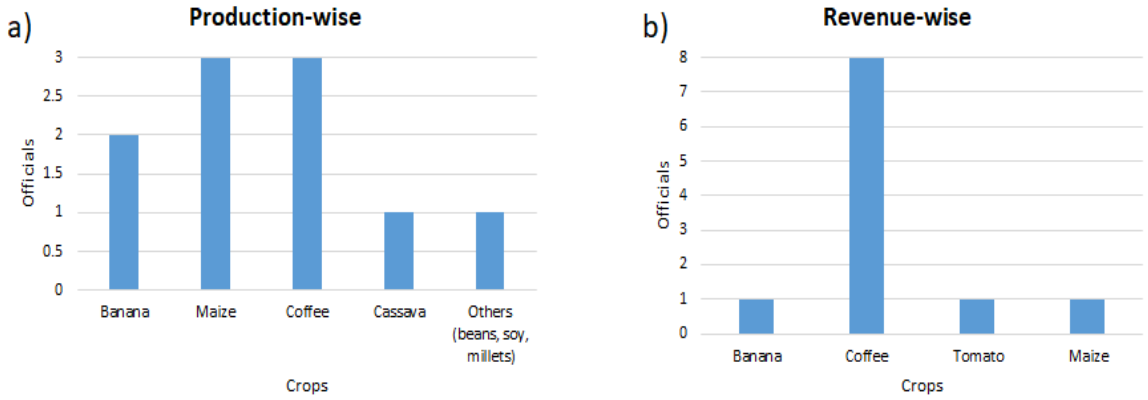

Figure 4. (a) Responses of the officials on the important crops of Uganda in terms of quantity of production (b)The importance of coffee as a cash/ revenue crop for the economy of the country but more importantly, the livelihood of the small-scale farmers.

Figure 5. Shows the different motivations of farmers behind having coffee as their main crop, with income generation possibilities as the main motive. Three farmers also indicated their motivation for coffee because of its perennial nature. And, one farmer talked about its potential to beautify the land.

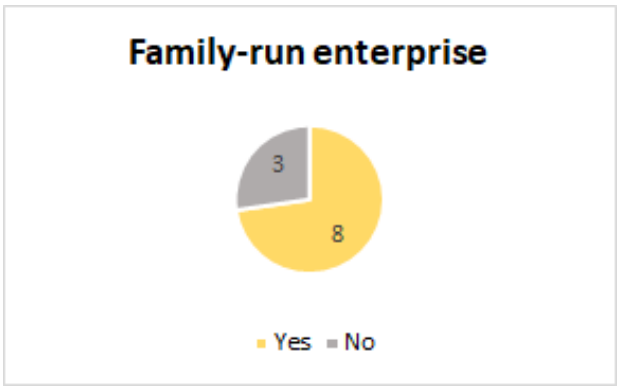

Figure 6. Shows that the majority (8 out of 11) interviewed farmers consider coffee as a family-run enterprise. This involves contributions from all members of the family, resulting in revenue that helps secure their livelihood.

On the challenges faced by the farmers in coffee cultivation, all the farmers (11 out of 11) answered pests, especially referring to the BCTB as the major challenge. Additionally, 5 farmers also talked about marketing issues caused by unstable prices in the market and lack of affordability of tools and equipment, and chemicals for spray. Coffee diseases were mentioned by 4 out of 11 farmers, mainly pointing out the coffee wilt disease (Figure 7). In addition to the four major challenges, the farmers had also mentioned other challenges such as weather conditions, pre-harvesting of beans due to theft, soil infertility and a few others. The online survey also showed that BCTB was regarded as the most important pest of coffee in Uganda both in the spread and economic losses (Figure 8a & b), followed by several others, such as the coffee red blister, coffee wilt, coffee berry borer, and others. All but one farmer answered that BCTB is the major pest in Uganda.

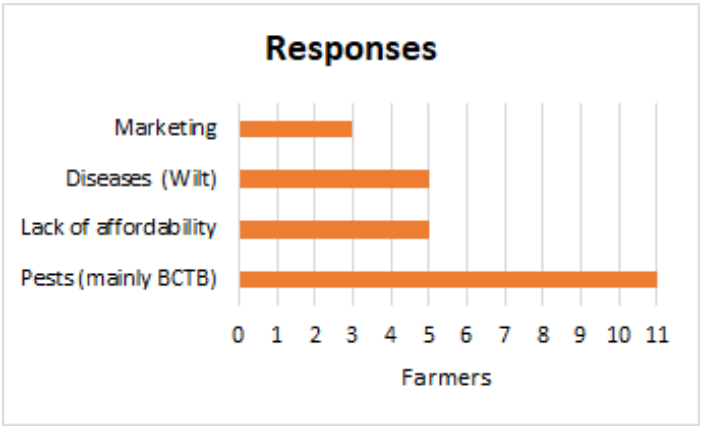

Figure 7. Responses of farmers on the major challenges in coffee cultivation (n=11). Farmers were able to choose multiple issues, both on and off-field, as major challenges, of which all the 11 interviewed farmers chose pests, especially referring to the BCTB as their most concerning challenge of them all. Marketability and lack of affordability of tools and equipment were some other off-field challenges.

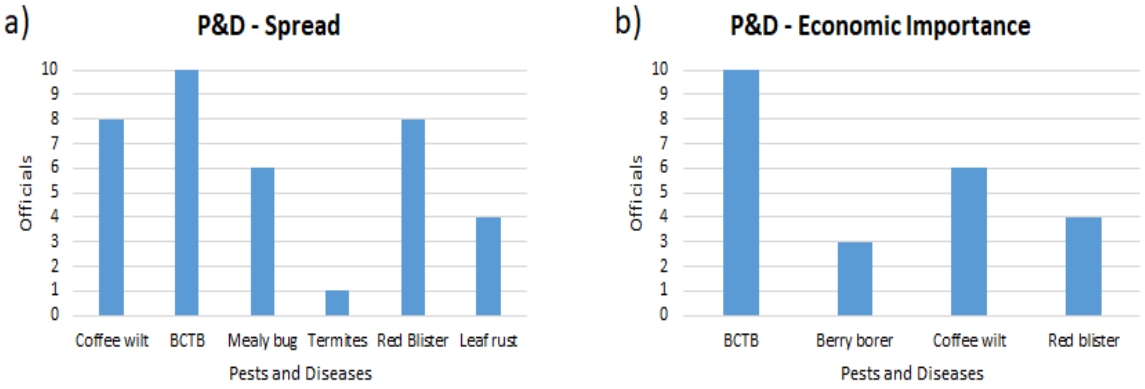

Figure 8. Perceptions of officials based on the online survey on (a) types of pests and diseases of coffee with regards to their wide distribution in the country; (b) the economic losses due to pests and diseases of coffee in Uganda.

All farmers except one had problems with the BCTB and its impact on the loss of final yield of coffee (per season) is given below (Figure 9). One of the farmers stated 'zero' loss due to BCTB. Although he mentioned that this was due to regular management operations, I noted that his primary source of income was teaching. He therefore did not invest much time in looking at losses and therefore likely grossly underestimated the impact of BCTB. The BCTB targets the coffee twigs and has different symptoms based on the stage of infestation. The most commonly noted visual symptom of attack on the field by both the farmers (8 out of 11) and officials (10 out of 10), is the drying and blackening of twigs. Other symptoms include yellowing of leaves, which can be found when the trees are under stress before the drying happens, and holes in the twig, the first symptom of the BCTB (Fig 10 a&b). Similarly, regarding the control measures of the BCTB, the opinions were similar between respondents belonging to both target groups. Several management practices were mentioned, of which the most common ones mentioned were cut and burn, pruning, and chemical control. Of the three, cut and burn was the most preferred management practice by both target groups, 9 out of 11

farmers and 5 out of 10 officials. Three out of 10 officials recommended the use of chemicals as an effective control, especially Imidachoprid and Tebuconazole which is insecticide and fungicide respectively, whereas, the use of chemicals reported by farmers as a mitigation measure is very low (1 out of 11, Figure 11 a&b).

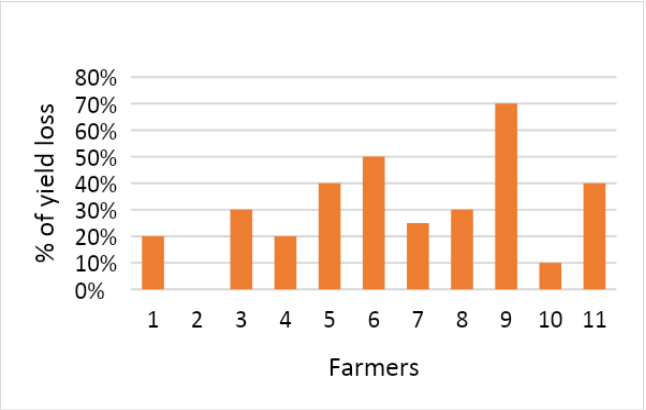

Figure 9. Shows the rough estimates of farmers on the harvest loss faced every season, mainly because of BCTB attack. all individual responses are displayed to illustrate the variation of damage between farmers. Farmer two believes to lose zero harvests because of his proper management and never took effort in calculating it.

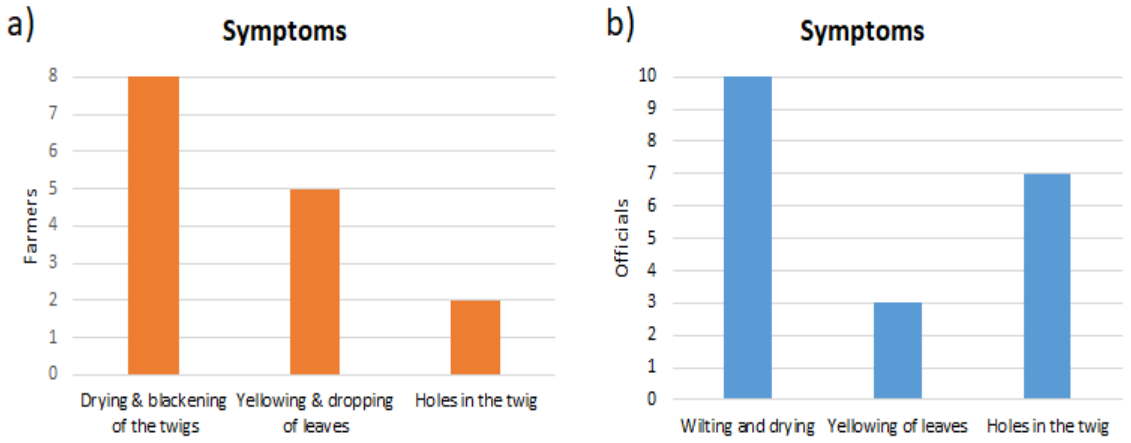

Figure 10. (a & b): Responses of the farmers and officials on the symptoms of BCTB attack on coffee trees.

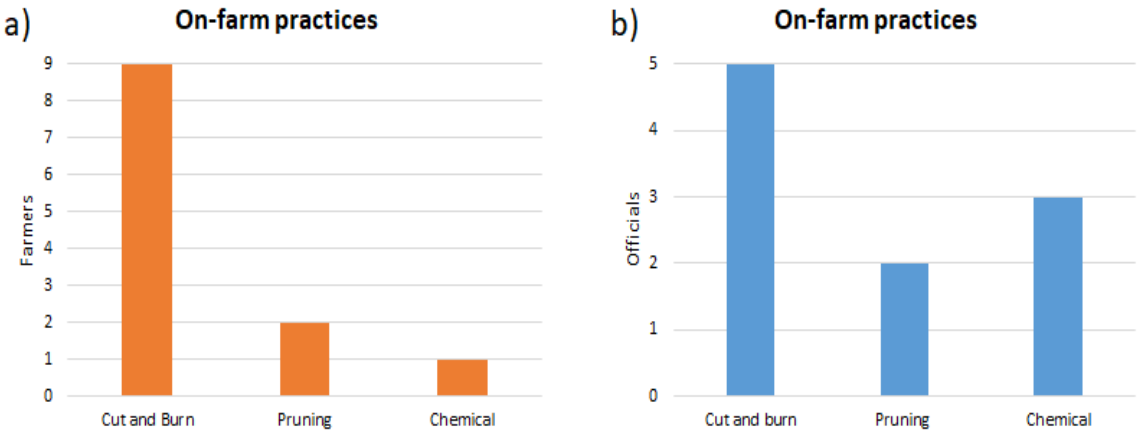

Figure 11. (a) The on-farm management practices performed by farmers; (b) the recommended practices by the officials to control the spread of BCTB on the field

Shading is also another important management strategy to control the BCTB attack. The views of farmers and officials on the influence of shade levels on BCTB infestation rates varied among the groups. Eight out of 10 officials said that the infestation level was higher under shaded conditions. One official responded that irrespective of shading conditions, the infestation will be equal. Among the farmers, 5 of them answered higher levels under shade, 4 of them answered under non-shade conditions and 2 said that they were not sure about this. (Figure 12). One of the farmers who mentioned higher infestations under non-shaded conditions perceived that direct sunlight helps in the survival of the pest. Whereas, all the farmers who chose shaded conditions implied that it is the shade that gives good conditions for the pest to survive.

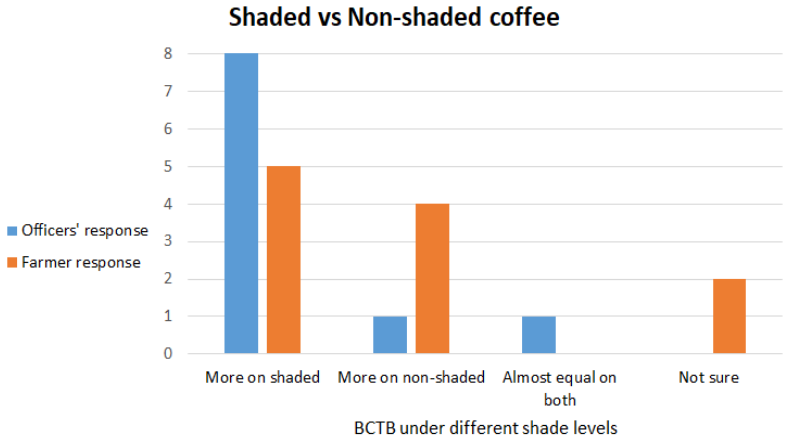

Figure 12. The views of farmers and officials on the infestation levels of BCTB under shaded and non-shaded conditions.

Farmers intercrop coffee with different types of trees as a source of food or income or both. Banana is the most common intercrop with coffee providing both food and additional income to farmers. Farmers also mentioned that the reason for having an intercrop with coffee was mainly to get the motivation to do on-farm activities, and have multi-functional use of the land. Musizi *(Maesopsis eminii)* and Mugairei *(Albizia chinensis)* are the two common shade trees intercropped with coffee (Figure 13 a). Ten out of 11 farmers had the above-mentioned trees on their field primarily for shade purposes, one farmer for the firewood and weed control, and two of them used leaf litter from these trees as green-manure for other crops. However, both the above-mentioned trees were considered to play a role of an alternate host for the BCTB, as pointed out by majority of the officials (Figure 13 b). One of the officials was of the view that since these trees had softwood, and another official indicated that they have similar twigs as coffee, making them easy for BCTB to penetrate.

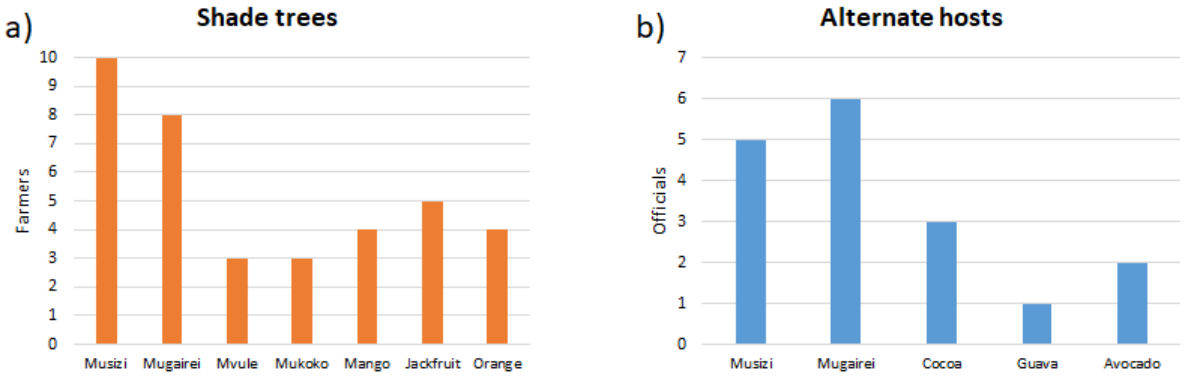

Figure 13. (a) shows the variety of shade trees at farmers' garden; (b) types of potential alternate hosts for BCTB by the officials.

All the 11 interviewed farmers had BCTB on their farm and their trees had been exposed to BCTB infestation ranging from the past 3 to 20 years. When asked about the extent of the problem at the current times compared to the past years, 9 out of 11 farmers answered that the BCTB infestation had increased. Reasons stated were many such as deforestation, weather patterns, and no proper control options. However, two farmers trusted that proper shade management and pruning could be the reason for the reductions in BCTB. Eight of the 10 officials also answered that the BCTB infestation had increased. The major reasons mentioned by the officials were lack of community-based approach and the inefficient management practices by the farmers. However, 1 official said that there was no change in the extent of the infestation (Figure 14 a&b). Farmers as well as officials pointed to the need for new improved strategies to control BCTB. In line with the significance of BCTB in livelihoods, the majority of the farmers wished for access to chemical control as the solution to control BCTB (6 of 11). Two of them suggested additional research could be helpful in bringing new solutions (Figure 15). All the farmers are very welcoming and enthusiastic about new innovations to be tried out in their fields, hoping to suppress the pest. However, the officials suggested a community-based approach as a required and efficient way out to limit the re-infestation of this pest on the coffee plantations. But there seemed to be an absence of the transfer of information between these two groups. All farmers except one rated the extension service delivery by the officials as 'Bad'. The farmers said they were in need of technical advice, but this was not provided with any kind of advisory service by the officials. On the other hand, the majority of the officials answered that they keep track of how things are happening, and provide advice to the farmers whenever it is required (Figure 16 a&b).

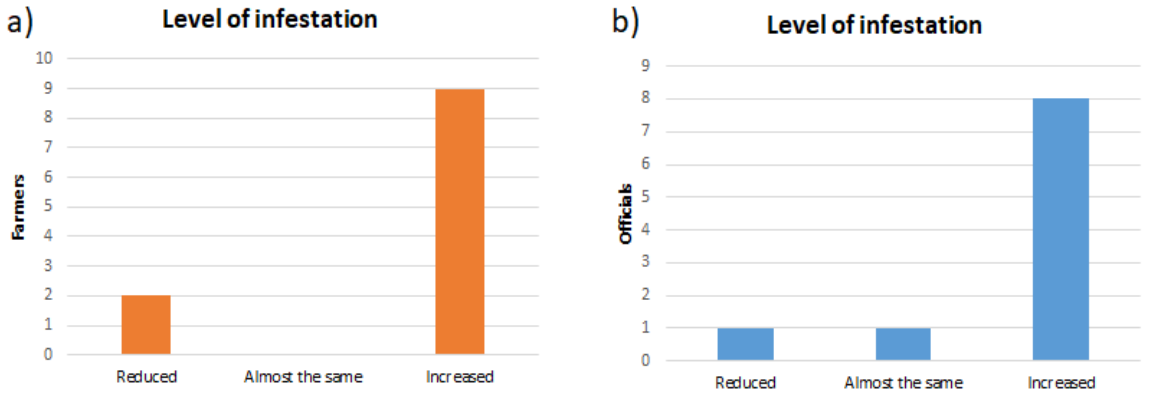

Figure 14. (a & b): Views of (a) farmers and (b) officials on the current infestation trend of BCTB compared to past years.

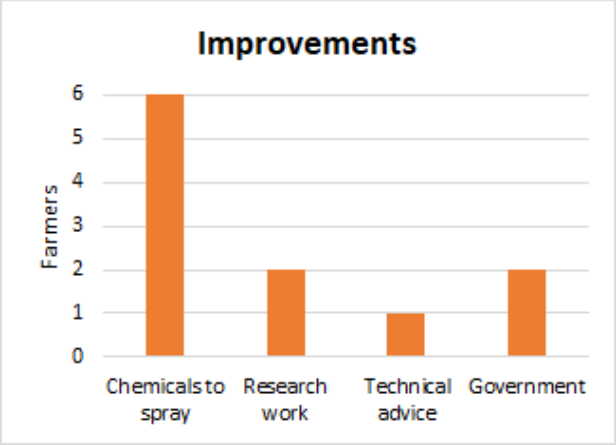

Figure 15. The views of farmers on the necessary improvement areas to deal with the major pest, BCTB; of coffee

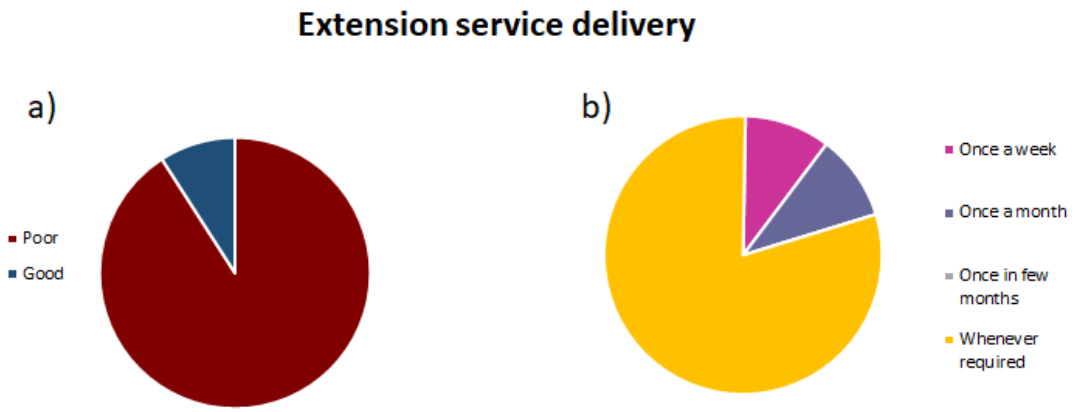

Figure 16. (a) The farmers' rating on the extension service delivery to their farm. (b) The frequency of field visits made by the officials for providing guidance to the farmers as indicated by the officials.

3.2 Repellency trials with verbenone

Field trials were conducted to test the repellency of BCTB to an anti-aggregation signal of other ambrosia beetle species, verbenone, in a slow-release wax-based matrix *Splat.* Grouped trees (9 coffee trees per quadrant) in all the eight plots with *SplatVerb* trees (treatment) had significantly lower BCTB infestations than the eight control plots (n=8, *P*-value = <0.0001, GLMM with a quasibinomial distribution, Fig 17a). The level of infestation was 60% (± 2.82 SE) lower in the treatment than in the control. *SplatVerb* applied to a stand of nine coffee trees (grouped) in all the paired plots showed the same trend in the infestation levels. Having further discussions, I also found that the proportion of infested twigs on the outer and inner half of both treatment and control did not differ in infestation levels (*P*-value = 0.7948 & 0.2074 for the treatment and control plots respectively, GLMM with a quasibinomial distribution, Figure 17b).

I also tested for the proportion of BCTB infested twigs on the upper and lower part of the trees in both the plots. Figure 14c shows that the percentage of infested twigs in the lower part of the trees was significantly higher than the upper part, in both control and treatment plots (*P*-value = 0.0001 & <0.0001 of the treatment and control plots respectively, GLMM with a binomial distribution, Figure 17c).

Finally, I also assessed whether *SplatVerb* applied to randomly chosen single coffee trees in a mixed stand coffee plot would reduce the infestation rates in that tree and found no significant reduction in the BCTB infestations between *SplatVerb* trees (treatment) and no *SplatVerb* trees (control) (n=12, *P*-value = 0.337 (>0.05), GLMM with quasibinomial distribution, Figure 18).

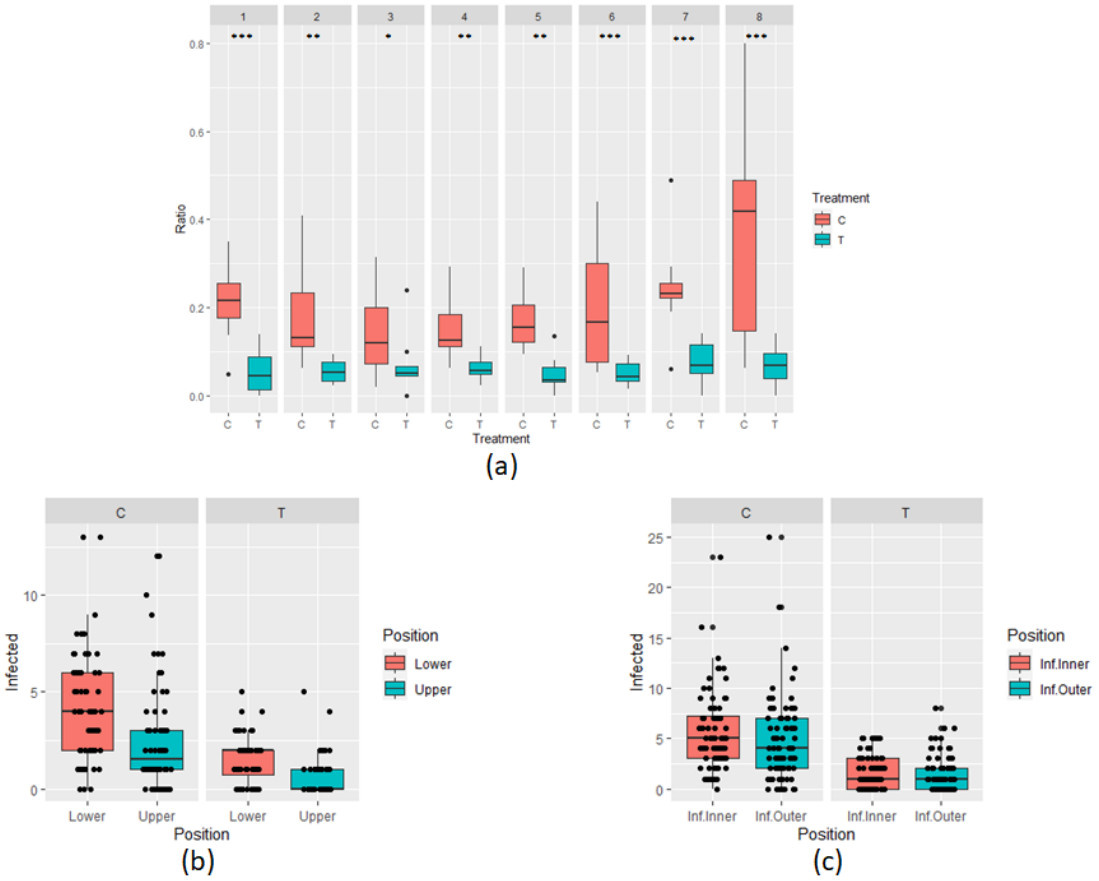

Figure 17. (A): Field trial results show the difference in the infestation levels of the Black Coffee Twig Borer (BCTB) upon the influence of Splat-Verbenone in all the eight paired plots. Boxplots containing median, and interquartile ranges show the proportion of infested twigs in the treatment (trees with Verbenone) and control (untreated trees) plots. The dots represent the outliers. '*' in the graph denotes the level of significance in each plot (GLMM with a binomial distribution); (B) Boxplots of the percentage of infested twigs positioned on the outer half and inner half of the trees treated with *SplatVerb* (Treatment) and untreated trees (Control). The dots in the graph represent the individual trees in the field experiment. In the trees with *SplatVerb*, there was no significant difference between the outer half and inner half of the trees. The plots with untreated trees also did not differ significantly. The results were obtained by using a Generalized Linear Mixed Model with a quasibinomial distribution; (C) This figure containing box plots shows the results of the percentage of infested twigs located on the lower part and upper part of the trees treated with *SplatVerb* (Treatment) and untreated trees (Control). The dots in the graph represent the individual trees in the field experiment. In the trees with

SplatVerb, there is a highly significant difference (***) between the number of infested twigs on the lower part and upper part of the trees. GLMM with a quasibinomial distribution was the model used for the analysis.

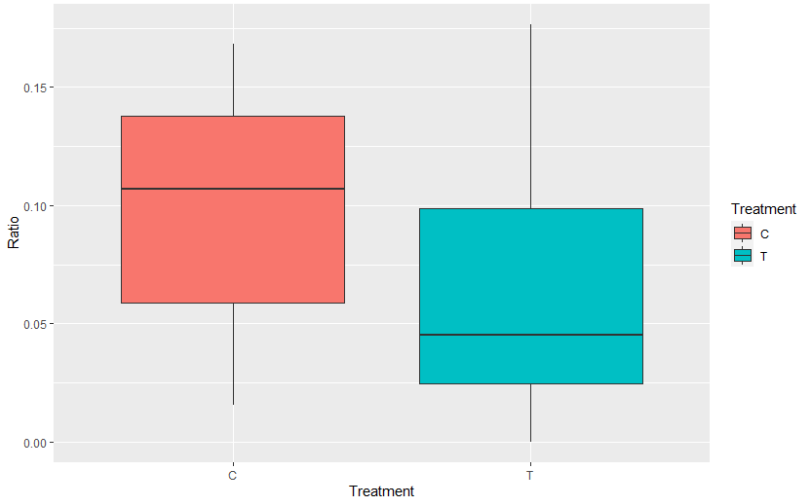

Figure 18. The level of BCTB infestation in isolated *SplatVerb* treated trees (treatment,n=12) compared to untreated trees (control, n=12). The infested twig count in the treatment and control trees did not differ significantly (P-value = 0.337 >0.05) GLMM with binomial distribution was employed.

3.3 Bottle traps with 'Waragi' as an attractant

Integrated within the setup of verbenone field trials on grouped trees, I installed bottle traps on the center tree in all the treatment plots. These traps on the center of the plot were primarily installed for estimates of the local BCTB population. But, unfortunately, due to the poor weather conditions and low populations of the beetle at that time, catches were insufficient to be of use for further analysis.

3.4 Potential loss faced by farmers due to BCTB damage

Based on our field trial data, each of the smallholder coffee farmers faces an average loss of 11 twigs per tree per season due to BCTB attack. Assuming the same, a farmer is likely to face a potential overall loss of 18.96 % in the final coffee harvests per season. According to the information from ACSA, coffee contributes to about 60% of the total family income of an average Ugandan coffee farmer (assuming 100% production per season). This implies that a loss of 18.96 % due to BCTB in the final coffee harvests ,causes a seasonal income loss of 11.37% due to BCTB infestations to an average smallholder farmer.

4. Discussion

The Ugandan coffee production sector is regarded as the backbone of the agricultural economy of the country and also of the farmers. It reaches an annual production of approximately 282000 tons, standing 8th globally. According to the UCDA, Uganda's coffee roadmap is increasing exponentially, as the country is aiming to increase the current 3.5M bags to 20M bags by the year 2030 (ugandacoffee.co.ug). The sector plays a vital role in sustaining the livelihoods of the close to 2 million coffee growers and their families, standing as their major source of income (Bussolo et al. 2007). However, coffee cultivation faces a series of threats throughout its production process. One of the major problems to the farmers comes from the range of pests and diseases, as these cause a huge reduction in the yield and quality of coffee beans produced, causing a steep drop in income generated. This study focussed on the black coffee twig borer (BCTB), regarded as the major coffee pest in Uganda by earlier published studies (Kagezi et al. 2019), and, as shown here, also by the farmers and advisers. I sought to explore the potential to develop a novel agroecological strategy to control the BCTB population, grafted on the principle of a well-established pest control strategy, push-pull, widely used in maize intercropping systems in Africa (Cook, Khan, & Pickett. 2007). As a first step, I tested the possibility of repelling the insect using an anti-aggregation signal embedded in a wax-based matrix, SPLAT. The field trials showed that verbenone alone is capable of significantly suppressing BCTB populations. The field trial was accompanied by extensive surveys among farmers and advisers in order to evaluate dissemination of information between stakeholders, and possible improvements in the communication chain in the sector to aid dissemination of knowledge and adoption of innovative methods.

4.1 Economic significance of coffee

Coffee production dominates Ugandan agriculture, both in terms of production and economic significance. In the majority of farmer households, coffee cultivation is seen as a family-run enterprise where all members of the family contribute to the entire production process. Physical tasks such as digging the field and weeding are usually taken care of by the adult males and children in the family. Women mostly perform the bean harvesting and drying. The main motivation for farmers to continue coffee cultivation is because of the solid return in revenue that coffee provides. It is their most important source of income, and pulls them out of poverty by taking care of basic family needs, paying school fees for children, and saving money for health expenses, and so on (Vellema et al. 2015).

4.2 BCTB as the main challenge influencing coffee yields

The majority of the Ugandan smallholder farmers operate independently without being a part of an organization or union. This makes farmers' deal directly with middlemen and their exploitation, which poses a huge marketing challenge for the farmers. Thus, farmers end up in the cycle of poverty, as they are paid little for their efforts (ugandacoffee.co.ug). Beyond socioeconomic complexities, the economic stability of coffee production is jeopardized by a range of pests, with Ambrosia beetles of the family Scolytidae being the worst. Two species exist: the coffee berry borer (CBB), *H. hampei*, and the black coffee twig borer, (BCTB), *Xylosandrus compactus*. The CBB, a specialist on coffee spp., is native to Africa but invasive globally. In contrast, BCTB is a generalist species from Southeast Asia (Egonyu et al. 2017), which has spread globally, including Africa (Kagezi

et al. 2013). Both beetles hinder the production of coffee and endanger rural livelihoods. However, in Uganda, the BCTB constitutes the most significant threat, as this species primarily infests robusta coffee (*C. canephora*). Wang et al. (2015) describe the BCTB damage on robusta coffee trees as a major limiting factor on the quality and quantity of beans produced, along with the high age of coffee trees. This was echoed by our interviews among farmers and officials, which described the impact of the insect as 'devastating'. All the farmers involved in the study have been struggling to effectively manage the BCTB damage because of its fast-spreading nature for the past 5 – 20 years (own research, Kagezi et al. 2013). Furthermore, farmers also reported regular yield losses in their final harvests ranging from 20% to 70% per season, which is a significant loss for the small-holder producers since coffee production is the primary means of income generation (Bussolo et al. 2007). To see an improvement in the situation, farmers must pay very close attention to the adoption of control measures.

4.3 Current management practices appears not sufficient for BCTB management

The management practices performed by the farmers are very similar to the officials' recommendations. The most common visual-based control is known as the 'cut and burn'. This is done by scouting and removal of twigs under attack, followed by burning. The cut and burn technique is always performed as a post-established infestation control that can only help remove the insects to a small extent. In some cases, we observed that farmers removed the infested and wilting twigs and stored them either in sheds, in or close to the coffee fields, for later use. This provides only a temporary reduction in the local infestation rate as the female beetles have the capability to fly longer distances and re-establish in the coffee plot (Vanderlaan & Ginzel. 2013). However, this technique coupled with early detection of the attack can prove to be a better way of reducing the spread of BCTB. Early detection required scouting for the entry holes in the twigs, which is a symptom of attack before the twigs turn black. This is, however, little practiced given the time it takes. The farmers in Uganda do practice the cut and burn extensively as it is less knowledge-intensive and also serves their fuel needs, especially for cooking and water heating. This saves the cost for them to buy from an external source instead. Other management practices, such as pruning, are primarily done to trim the unwanted branches and to reduce shade. Pruning also seems to lower the chance for attack by the BCTB if combined with early detection of entry holes (Kagezi et al. 2013). Furthermore, three officials who responded to our online survey recommended the use of chemicals for effective control. However, the use of chemicals as a mitigation measure is potentially low for farmers, primarily because of the lack of affordability of the products (personal communication).

Another important practice is shade management (Hultman. 2016). Coffee in Uganda is traditionally grown in agroforestry settings (worldagroforestry.org) with a wide range of tree species intercropped mainly for the purpose of shade. Shaded coffee systems yield superior quality of beans to sun-exposed monoculture coffee (Vaast et al. 2016; Muschler. 2001). However, shaded coffee is also conducive to beetle development, if not properly managed. According to Kagezi et al. (2013), over-shading of coffee trees further facilitates the intensity and spread of this pest, as BCTB also prefers shaded over sun-exposed twigs (see also our results discussed later on). Several officers in our online study also indicated that shade provides a favorable microclimate for the insect's development. One of the officers also mentioned that shade increases humidity levels which in turn

increases the breeding rate of BCTB. This was also suggested by Anuar (1986), that higher moisture levels can favor the growth of the inoculated 'ambrosia' fungus. In contrast, almost half of the interviewed farmers thought that shading decreases infestation rates. This clearly shows the prevailing misconception among the farmers that needs attention.

However, it is not the only shade that favors BCTB infestation, but also the kind of shade tree on the farm. A variety of shade trees intercropped with coffee can also act as an alternate host for the BCTB, as this is a polyphagous pest having a host range of more than 200 plant species (Greco & Wright. 2012). Hence, much thought will need to be given to the type of tree species that farmers include as shade trees on their farms, in order to avoid this unwanted source of spread. Our study shows that Musizi (*Maesopsis eminii*) and Mugairei (*Albizia chinensis*), the two common intercropped tree species with coffee by the farmers, can act as hosts as stated by the officials. Studies concur this, with *A. chinensis* (Kucel et al. 2011; Kagezi et al. 2015) and *M. eminii* (Kagezi et al. 2020) acting as alternative hosts for the BCTB. Hara et al. (1979), demonstrated that avocado is another tree that can be a host to BCTB. This was confirmed by two officials in their responses. Unfortunately, farmers are generally unaware of alternative hosts for the BCTB. These trees are therefore not scouted for the insect and hence serve as inocula for reinfestation. This clearly shows the varying levels of understanding that farmers have from the officials and it is important to bridge this gap thoroughly. However, the information should be conveyed in such a way as to avoid farmers to divert their management practices and adopt unsustainable measures, for example, cutting back of all such trees from the field and compromising the environmentally sustainable agroforestry practices.

4.4 Climate change and the need for sustainable alternatives

Another aspect to note is the seasonality of the pest. All the participants in the survey pointed out that the level of BCTB infestations are steadily increasing over the years. This may in part be attributable to change in climatic patterns which likely exacerbates the intensity and spread of the pest, as heat and water stress increases the susceptibility of trees to attack Scolytidae beetles in general (Seidl et al. 2016; Gillette & Fettig, 2021), and we suspect BCTB as well. Bukomeko et al., (2018), also showed that, indeed, the level of BCTB infestation is climate-dependent, and the change in environmental conditions might strongly influence future BCTB dynamics (Teodoro et al. 2008). This especially needs sustainable adaptation strategies to perform better to the changing climatic conditions.

The search for economically and environmentally sustainable alternatives is extremely critical to support not only small-scale coffee production but also the rural livelihoods of the smallholder farmers in general. Therefore, here I explored a novel odor-based intervention strategy grafted onto the push-pull technique, for the management of this pest by testing the possibility of using verbenone, an anti-aggregation signal of bark beetles (Hunt & Borden, 1990), for use in integrated BCTB control settings. Similar to most other insects, the majority of Scolytidae beetles strongly rely on odors in finding suitable hosts (Pitman et al. 1968). This study was the first trial to assess whether verbenone could potentially act as a 'push' component of the push-pull strategy. As there are no studies reported on repellency of BCTB or push-pull-based control strategies in general for BCTB control, this study served as a proof-of-concept for the use of repellence in supporting future push-pull methods against the BCTB.

The use of verbenone as a tool in bark beetle pest management strategies has built considerable interest over more than half a decade or so (Lindgren & Miller, 2002). Verbenone is a resultant product of oxidative microbial degradation of verbenol, and the conversion process is facilitated by the symbiotic microorganisms associated with bark beetles, when there is higher exposure to oxygen. Verbenol is an aggregation pheromone of several Scolytidae bark beetle species of pine and spruce trees (Gillette & Fettig, 2021, Lindgren & miller 2002) and is synthesized from host tree defense (alpha-pinene) and/or *de novo* by the insect (Pitman et al. 1968). Also, Pitman et al. (1968), showed that these components, when acted independently, were not able to induce mass aggregation, and stated the occurrence of an unknown mechanism of interaction between these components to orient the insects to the new host trees. Verbenol is usually released by the female beetles, for example, in *Dendroctonus spp.* (Scolytidae), whereas, in certain *Ips* species, they are released by males following their feeding on the tree tissues (Brand et al. 1975). However, the general mechanism of pheromone release is through defaecation (Pitman et al. 1968). Verbenone, on the other hand, takes the opposing role of the aggregation pheromone verbenol, as it interrupts the movement of beetles to the aggregation points (Hunt & Borden, 1990). However, it is not known if BCTB releases and or uses verbenol as an aggregation pheromone in the first place. In fact, the mechanism of BCTB spread to, and infestation of new host trees. Given that verbenone strongly reduces infestation by BCTB, I suspect that also this Ambrosia beetle species uses verbenol as a pheromone. The results serve as a proof-of-concept of the repellence of verbenone for BCTB control and provide incentives to further research the potential of this compound in reducing BCTB infestation.

It is also important to note the limitations of using verbenone. In this study, *SplatVerb* seems to be very effective when applied in a stand of nine trees, but not when applied on single, spaced-out trees, indicating that verbenone is effective in offering spatial repellence only in concentrated stands. This also indicates that verbenone may also be effective in BCTB reduction when applied over larger areas, that is, a community-based application in a smallholder coffee production setting. The addition of a 'pull' component (such as in maize intercropping, Khan et al. 2014) in combination with verbenone, would likely further augment the effectiveness. However, the complexity of the coffee cropping system also raises questions, For instance, it is unknown whether verbenone needs to be also applied to other non-coffee trees that function as alternative hosts, as these trees possibly disrupt the spatial repellence. or alternatively that these trees could be used as catch trees. This all needs further investigation.

I also looked at the distribution of BCTB infestation within the tree canopy. Higher BCTB numbers were found on the lower part of the tree compared to the top showing their preference for shade. The same was pointed out by the advisers. I focused only on young trees for easy monitoring purposes. This was contrasting to Kagezi et al. (2013), where the highest number was at the top and the least number was in the lower portions. This could be because of senescence and pruning off of mature twigs from the lower part for maintenance, but the size and age of trees were not clearly mentioned in the study. As opposed to older trees, the number of twigs on young trees on the lower and the upper parts did not vary much and remained still fresh. This indicates that the beetles preferred the lower parts clearly because of the micro-climatic conditions provided by shade.

Similar to the use of verbenone as a spatial repellent, previous studies have also identified the potential of different aromatic plants performing similar roles as the verbenone in managing pest populations and reducing infestations (Figueroa, 2019). In bark beetles, a BCTB relative, volatiles released from non-hosts, such as deciduous trees can also disrupt host finding (Jactel et al. 2001; Schlyter. 2012; Unelius et al. 2014). Based on these reports, I planned to study the potential of these non-host volatiles to augment the effect of verbenone or even as a standalone locally-available alternative. Different trap combinations of essential oils from locally available aromatic plants such as lemongrass, *Cymbopogon citratus,* and marigold, *Tagetes spp.,* with or without verbenone were selected for the trial. These essential oils have been previously studied against other insects for repellence. For example, *Cymbopogon citratus* has mostly been tested for mosquito, sandfly, and biting fly repellence, whereas *Tagetes spp.,* has been tested mostly for its insecticidal properties (Figueroa. 2019). Such approaches do not necessarily result in complete pest control, but when coupled with proper on-farm management practices (Gillette & Fettig. 2021), has every potential to provide farmers with a sustainable alternative to control BCTB. Therefore, having received only a little attention in pest control, it is still well recognized that the repellence caused by the non-host volatiles can play an integral part as a tool in designing sustainable pest control strategies (Figueroa. 2019). In addition to the above-mentioned repellent combinations, I also designed traps to assess the potential of a known attractant, Waragi (a local alcohol product), to serve as a 'pull' and further lower infestation levels. Studies have already reported on the potential of ethanol and other associated host-derived volatiles as baits to attract wood-boring beetles to traps (Montgomery & Wargo. 1983). Time constraints and low BCTB populations at the time of the trial prevented me from executing this part of research, thus, will need to be executed in subsequent studies.

4.5 Problems in the dissemination of knowledge

Besides novel and sustainable intervention strategies, communication and adoption strategies are equally critical for novel sustainable intervention methods to reach growers. For new strategies of BCTB control to reach farmers, external assistance is required such as from the advisory services. Currently, coffee farmers in the Kamuli district are dissatisfied with the extension service delivery from the officials, as they sense the need for external assistance to control this menace. At the same time, lack of resources among farmers is preventing them from reaching out for advice even if they wanted to. On the other hand, the officials seem to be satisfied with their extension service efforts. The reason for the discrepancy between growers and officials may stem from growers who are expecting support and innovation to reduce the impact from BCTB, whereas on the other hand, advisors are content with the level of adoption of available methods and are having no further management practices to offer. This indicates a clear disparity in expectations between the two groups and a need for focused efforts to bridge this gap in the communication chain.

4.6 Organic production - a default setting in Uganda

The majority of coffee growers are resource-poor farmers and remain without access to information and technology, as this was also reflected in this study. The farmers in the study areas were predominantly small-scale organic growers by default primarily because of limited access and the high cost of pesticides. However, with the increased pressure of BCTB, the majority of the farmers currently intend to use pesticides hoping to bring down the pest population. This is also facilitated by

discussions at national level about promoting and lowering the prices of pesticides to provide farmers access (personal communication). Having little access to information, they are neither aware of the relative ineffectiveness of insecticides for burrowing insects, nor of the significant long-term repercussions of using chemical control methods. They thus perceive the use of insecticides as a valid and effective way of controlling the BCTB. However, given that coffee is grown in biodiversity-rich agroforestry settings (Oduol & Aluma. 1990; Tumwebaze & Byakagaba. 2016), the application of insecticides would have disastrous impacts on the ecosystems. Fortunately, the urgency of BTCB prompts farmers to be very welcoming to testing new ideas and innovations in their fields. This opens up opportunities for developing sustainable alternatives. The time window for finding these alternatives is though very restricted and needs fast-acting. I hope that the work set out in this thesis contributes to the development of such a sustainable alternative.

5. Future research

Coffee is an age-old practice among smallholder farmers and is a very important source of income. It is, therefore, important to provide farmers with effective and sustainable control measures, particularly since this pest is increasing over the years. The current study on finding sustainable strategies to the BCTB control, was restricted to smaller-scale tests, as I was time and resource-limited. Since this study has shown the efficacy of Verbenone as an effective agent to control BCTB infestation, field trials will need to be scaled-up by taking into consideration other factors and not just the age of coffee trees, as in this study. For instance, shade is one of the integral features of small-scale coffee gardens in the country, beneficial to both quality of coffee and incidence of BCTB. The amount of shade in a coffee garden depends on the number and type of shade trees grown. Hence, future studies will have to focus on the spatial distribution of shade levels pertaining to different trees and their influence on the BCTB population. Further, some of the intercropped shade trees also serve as alternate hosts for the BCTB, which needs careful attention in future studies. Studies should also focus on older trees in the region, as most coffee growers have comparatively older trees, as opposed to this study. Expansion into other robusta coffee areas may also be needed, considering the various local effects. For instance, in Masaka, considered one of the major coffee-producing districts in the country, where a larger number of farmers tend to use chemicals as a control measure (personal communication, own research).

This study clearly shows that verbenone can reduce BCTB populations when applied on grouped trees rather than single trees. This warrants an area-wide application approach as opposed to single fields, as each field borders other coffee fields in this small-scale production setting. Verbenone shows potential for wider-scale usage. I recognize that the application of a repellent alone may not be sufficiently effective. Rather, it can be part of a set of sustainable tools that need to be tailored to fit local conditions. For instance, verbenone *(SplatVerb)* as a spatial repellent for BCTB could serve as part of a push-pull strategy (Khan et al. 2014) in combination with attractants. A locally available and known attractant ‘Waragi’, in combination with catch trees (alternate hosts), the potential of which needs further investigation, should also be assessed for their potential in further lowering infestation in ‘push’ plots. Moreover, verbenone is a synthetic compound primarily used for experimental purposes. This makes verbenone use restricted, as it is not directly available for farmers in the Ugandan market. Therefore, future research should delve into the potential of using sustainable, locally available repellents from e.g. aromatic plants in managing the BCTB populations and reducing

infestations to provide easy access to farmers. A first step toward this could be conducting trapping assays with different combinations of essential oils from locally available lemongrass and marigold or blends of these. The potential synergies between these aromatic extracts and *SplatVerb* need attention too. These studies could possibly serve as a step forward in developing sustainable and alternative tools, perhaps, well fitted to local conditions and easily accessible for farmers to put into practice. Even though the push-pull technique may use natural products such as essential oils and ethanol products, that might reduce the need for chemical control, their effects on beneficials in unknown and needs careful attention. As much as the essential oils may reduce pest attack, they can also repel the beneficial insects, and similarly, ethanol products such as Waragi, might attract other insect taxa and cause an impact on biodiversity. The sustainability of potential control methods needs careful attention.

Furthermore, the use of verbenone in repelling ambrosia beetles of coffee could also be tested on CBB populations, as I expect that CBB (Hargreaves. 1935; Damon. 2000) uses similar cues for host orientation, like BCTB, which needs investigation. This opens up new possibilities to develop and expand this research into different coffee-producing areas, including the arabica coffee *(C. arabica).*

Finally, the surveys on the perceptions of the BCTB among the interviewed people yielded interesting results, but this was particular to one region because of limitations in time. In the future, mapping out coffee stakeholder networks throughout the country and identifying obstacles and potential ways of improvements will receive much attention, to facilitate innovations and their spread in sustainable coffee production in Uganda. Research will further identify how opportunities of local coffee value chain development including employment creation.

6. Conclusion

This research explored the potential of developing an odor-based intervention strategy grafted onto the push-pull technique for suppressing BCTB infestations in coffee gardens. It demonstrates the potential of verbenone (*SplatVerb)* in repelling the BCTB from coffee trees and reducing infestations by 60%. The results serve as a proof-of-concept for use of repellency in suppressing BCTB. This research also show that verbenone was effective when applied to a stand of coffee trees, but not when applied to single trees, indicating the need for a combination of a ‘pull’ component, such as the one developed for maize-intercropping systems (push-pull), also in Africa. To complement the spatial repellency of verbenone, studies on the potential attractants such as BCTB catch trees (alternate hosts) and attractant traps, need further investigation. In order to increase the accessibility and adoption of the products by farmers, future studies should focus on the possibilities of using locally available aromatic extracts as repellents and their potential synergies with verbenone.

This study also highlights the disparity in the perceptions regarding the extension of service delivery by the government officials to the farmers, indicating that outreach and access to technology are needed. This will help translate into better field operations, increased accessibility, and the adoption of new alternatives by farmers. Also, establishing farmer organizational units on a sub-county level or village level would likely ease the process of communication, while at the same time lowering the burden for the officials. This could also possibly bring down the middlemen exploitation as well because of the streamlined marketing channel. I also suggest that efforts on the management of host

trees by performing regular pruning, watching out for new incidence of infestation, and burning them can be one way to lower the BCTB spread. However, I recognize that this can be labor-intensive and prove to be economically challenging for the farmers as they might need external assistance to manage large trees. Finally, farmers are welcoming to new innovations in their fields, thus creating opportunities for developing sustainable alternatives, but this needs fast-acting.

7. References

Anuar, A. . (1986). Observation on damage by Xylosandrus Compactus in coffee as affected by shade and variety. *Mardi Res. Bull*, *14*, 108–110.

Batra, L. R. (1963). Ecology of ambrosia fungi and their dissemination by beetles. *Transactions of the Kansas Academy of Science (1903-)*, *66*(2), 213-236.

Bekele Tesemma, A. (2008). *Profitable Agroforestry Innovations for Eastern Africa*.

Bosselmann, A. S., Dons, K., Oberthur, T., Olsen, C. S., Ræbild, A., & Usma, H. (2009). The influence of shade trees on coffee quality in small holder coffee agroforestry systems in Southern Colombia. *Agriculture, Ecosystems and Environment*, *129*(1–3), 253–260. https://doi.org/10.1016/j.agee.2008.09.004

Braun, V., Clarke, V., Boulton, E., Davey, L., & McEvoy, C. (2020). The online survey as a qualitative research tool. *International Journal of Social Research Methodology*, 1-14.

Bukomeko, H., Jassogne, L., Kagezi, G. H., Mukasa, D., & Vaast, P. (2018). Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda. *Agricultural and Forest Entomology*, *20*(3), 327–333. https://doi.org/10.1111/afe.12265

Cook, S. M., Khan, Z. R., & Pickett, J. A. (2007). The use of push-pull strategies in integrated pest management. *Annual Review of Entomology*, *52*, 375–400. https://doi.org/10.1146/annurev.ento.52.110405.091407

Cooper P J M and Coe R. (2011). Assessing and addressing climate-induced risk in sub-Saharan rainfed agriculture *Exp. Agric.* 47 179–84

Damon, A. (2000). A review of the biology and control of the coffee berry borer, Hypothenemus hampei (Coleoptera: Scolytidae). *Bulletin of Entomological Research*, 90(6), 453-465. doi:10.1017/S0007485300000584

Egonyu, J. P., Baguma, J., Ogari, I., Ahumuza, G., & Ddumba, G. (2017). Host preference by the twig borer Xylosandrus compactus (Coleoptera: Scolytidae) and simulated influence of shade trees on its populations. *International Journal of Tropical Insect Science*, *37*(3), 183–188. https://doi.org/10.1017/S174275841700008X

FAO. (Factsheet). Food and Agriculture Organization - https://www.fao.org/3/i8359en/I8359EN.pdf

Figueroa, I. (2019). Ethological control of the Mediterranean fruit fly Ceratitis capitata (Wied.).

Gillette, N., & Fettig, C. (2021). Semiochemicals for bark beetle (Coleoptera: Curculionidae) management in western North America: Where do we go from here? *The Canadian Entomologist*, 153(1), 121-135. doi:10.4039/tce.2020.61

Greco, E., & Wright, M. (2012). First Report of Exploitation of Coffee Beans by Black Twig Borer *(Xylosandrus Compactus)* and Tropical Nut Borer *(Hypothenemus obscurus) (*Coleoptera; Curculionidae: Scolytinae) in Hawaii.

Gugliuzzo, A., Criscione, G., Biondi, A., Aiello, D., Vitale, A., Polizzi, G., & Tropea Garzia, G. (2020). Seasonal changes in population structure of the ambrosia beetle Xylosandrus compactus and its associated fungi in a southern Mediterranean environment. *PLoS ONE*, *15*(9 September), 1–13. https://doi.org/10.1371/journal.pone.0239011

Hara, A. H., & Beardsley, J. W. (1979). The Biology of the Black Twig Borer *, Xylosandrus compactus (Eichhoff),* in Hawaii *12*. *XIII*(1), 55–70.

H. Hargreaves (Government Entomologist) (1935) Stephanoderes Hampei Ferr., Coffee Berry-Borer, in Uganda, *The East African Agricultural Journal*, 1:3, 218-224, DOI: 10.1080/03670074.1935.11663651

Hultman, C. (2016). Black Coffee Twig Borer, *Xylosandrus compactus (Eichhoff)* on robusta coffee in Uganda - Impact of shade level on abundance of BCTB and knowledge levels about BCTB. 76.

Hunt, D. W. A., & Borden, J. H. (1990). Conversion of verbenols to verbenone by yeasts isolated from Dendroctonus ponderosae (Coleoptera: Scolytidae). *Journal of Chemical Ecology*, *16*(4), 1385–1397. https://doi.org/10.1007/BF01021034

Jactel, H., Van Halder, I., Menassieu, P. *et al.* Non-Host Volatiles Disrupt the Response of the Stenographer Bark Beetle, *Ips sexdentatus* (Coleoptera: Scolytidae), to Pheromone-Baited traps and Maritime Pine Logs. *Integrated Pest Management Reviews* 6, 197–207 (2001). https://doi.org/10.1023/A:1025775419193

Jassogne, L., van Asten, P. J. A., Wanyama, I., & Baret, P. V. (2013). Perceptions and outlook on intercropping coffee with banana as an opportunity for smallholder coffee farmers in Uganda. *International Journal of Agricultural Sustainability*, *11*(2), 144–158. https://doi.org/10.1080/14735903.2012.714576

Jayne, T. S., & Sanchez, P. A. (2021). Agricultural productivity must improve in sub-Saharan Africa *Science (80-.).* 372 1045–7

Judith, K., Godfrey, K. H., Abisagi, K., Patrick, K., Lilian, N., Ivette, P., & William, W. W. (2018). Farmers ' Knowledge of Pests and Diseases in the Coffee-Banana Agroforestry Systems of Mid-Eastern Uganda. 7(2), 109–119. https://doi.org/10.15640/jns.v7n2a12

Kagezi, H. G., Kucel, P., Egonyu, P. J., Nakibuule, L., Kobusinge, J., Ahumuza, G., ... & Chesang, B. F. (2013). Impact of the black coffee twig borer and farmers' coping mechanisms in Uganda. *11th African Crop Science Proceedings, Sowing innovations for sustainable food and nutrition security in Africa. Entebbe, Uganda, 14-17 October, 2013*, 285-292.

Kagezi, G. H., Kucel, P., Kobusingye, J., Nakibuule, L., Wekhaso, R., Ahumuza, G., ... & Kangire, A. (2013). Influence of shade systems on spatial distribution and infestation of the Black Coffee Twig Borer on coffee in Uganda. *Uganda Journal of Agricultural Sciences*, *14*(1), 1-12.

Kagezi GH, Kucel, P, Olango N, Tumuhaise V, Nakibuule L, Kobusinge J, Kabole C, Chesang F and Wagoire WW. 2016. Dynamics of black coffee twig borer damage on Robusta coffee in Uganda. In: Book of programme and abstracts, *NARO-MAK Joint Agricultural Dissemination Conference*, November 21-24, 2017, Munyonyo, Uganda, p. 92.

Kagezi, G., Kucel, P., Nakibuule, L., Kobusinge, J., & Katondi, A. P. (2019). Field-based Evidence of the Black Coffee Twig Borer infesting Maesopsis eminii in Coffee Agro-systems in Kiboga District, Uganda. *Uganda Journal of Agricultural Sciences*, *19*(1), 15-20.

Kagezi, Godfrey., Kucel, Patrick., Olango, Nicholas., Kobusinge, Judith., & Nakibuule, L., Nambozo, B., Olal, Sammy., & Wagoire, William. (2019). Pesticides used by farmers in the arabica coffee growing regions of Uganda. *African Journal of Food Agriculture Nutrition and Development.* 19. 14863-14872. 10.18697/ajfand.87.17725.

Karungi, J., Nambi, N., Ijala, A. R., Jonsson, M., Kyamanywa, S., & Ekbom, B. (2015). Relating shading levels and distance from natural vegetation with hemipteran pests and predators occurrence on coffee. *Journal of Applied Entomology*, *139*(9), 669–678. https://doi.org/10.1111/jen.12203

Khan, Z. R., Midega, C. A., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J., & Pickett, J. A. (2014). Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20120284.

Leufvén, A., Bergström, G., & Falsen, E. (1984). Interconversion of verbenols and verbenone by identified yeasts isolated from the spruce bark beetle Ips typographus. *Journal of Chemical Ecology*, *10*(9), 1349–1361. https://doi.org/10.1007/BF00988116

Lindgren, B. S., & Miller, D. R. (2002). Effect of verbenone on five species of bark beetles (Coleoptera: Scolytidae) in lodgepole pine forests. *Environmental Entomology*, *31*(5), 759–765. https://doi.org/10.1603/0046-225x-31.5.759

Milestad, R., Darnhofer, I., & Taylor, P. (2008). Building Farm Resilience : The Prospects and Challenges of Organic Farming Building Farm Resilience : The Prospects and Challenges of Organic Farming. *Journal of Sustainable Agriculture*, *0046*(November 2013), 37–41. https://doi.org/10.1300/J064v22n03

Miller, D. R., & Rabaglia, R. J. (2009). Ethanol and (-)-α-pinene: Attractant kairomones for bark and ambrosia beetles in the Southeastern US. *Journal of Chemical Ecology*, *35*(4), 435–448. https://doi.org/10.1007/s10886-009-9613-9

Milligan, M. C., Johnson, M. D., Garfinkel, M., Smith, C. J., & Njoroge, P. (2016). Quantifying pest control services by birds and ants in Kenyan coffee farms. *Biological Conservation*, *194*, 58–65. https://doi.org/10.1016/j.biocon.2015.11.028

Montgomery, M. E., & Wargo, P. M. (1983). Ethanol and other host-derived volatiles as attractants to beetles that bore into hardwoods. *Journal of Chemical Ecology*, *9*(2), 181–190. https://doi.org/10.1007/BF00988035

Muschler, R.G. Shade improves coffee quality in a sub-optimal coffee-zone of Costa Rica. *Agroforestry Systems* 51, 131–139 (2001). https://doi.org/10.1023/A:1010603320653

Musoli, P. C., Hakiza, G. J., Birinkunzira, J. B., Kibirige-Sebunya, I., Kucel, P., & Mukiibi, J. K. (2001). Coffee (Coffea spp.). *Agriculture in Uganda*, *2*, 376-436.

Ngoan, N. D., Wilkinson, R. C., Short, D. E., Moses, C. S., & Mangold, J. R. (n.d.). Biology of an Introduced Ambrosia Beetle, Xylosandrus compactus, in Florida. 872–876.

Oduol, P. A., & Aluma, J. R. W. (1990). The banana (Musa spp.)—Coffee robusta: traditional agroforestry system of Uganda. *Agroforestry systems*, *11*(3), 213-226.

Peter, A. (1990). *Coffee robusta:* 213–226.

Pitman, G. B., VitÉ, J. P., Kinzer, G. W., & Fentiman, A. F. (1968). Bark beetle attractants: trans-verbenol isolated from dendroctonus. *Nature*, *218*(5137), 168–169. https://doi.org/10.1038/218168a0

Pumariño, L., Sileshi, G. W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M. N., … Jonsson, M. (2015). Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic and Applied Ecology*, *16*(7), 573–582. https://doi.org/10.1016/j.baae.2015.08.006

Rabaglia, R. J., Dole, S. A., & Cognato, A. I. (2006). Review of American Xyleborina (Coleoptera: Curculionidae: Scolytinae) occurring north of Mexico, with an illustrated key. *Annals of the Entomological Society of America*, *99*(6), 1034–1056. https://doi.org/10.1603/0013-8746(2006)99[1034:ROAXCC]2.0.CO;2

Reding, M., Oliver, J., Schultz, P., & Ranger, C. (2010). Monitoring Flight Activity of Ambrosia Beetles in Ornamental Nurseries with Ethanol-Baited Traps: Influence of Trap Height on Captures. *Journal of Environmental Horticulture*, *28*(2), 85–90. https://doi.org/10.24266/0738-2898-28.2.85

Rosenzweig, C., Iglesius, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events - Implications for food production, plant diseases, and pests *Glob. Chang. Hum. Heal.* 2 90–104

Schlyter, F. (2012). Semiochemical diversity in practice: antiattractant semiochemicals reduce bark beetle attacks on standing trees—a first meta-analysis. *Psyche*, *2012*.

Seidl, R., Müller, J., Hothorn, T., Bässler, C., Heurich, M., & Kautz, M. (2016). Small beetle, large-scale drivers: How regional and landscape factors affect outbreaks of the European spruce bark beetle. *Journal of Applied Ecology*, *53*(2), 530–540. https://doi.org/10.1111/1365-2664.12540

Shively, G., & Hao, J. (2012). A Review of Agriculture, Food Security and Human Nutrition Issues in Uganda. *… University Department of Agricultural …*, (September), 1–42. Retrieved from http://ageconsearch.umn.edu/bitstream/135134/2/12-3Shively.Hao.pdf

Teodoro, A., Klein, A. M., & Tscharntke, T. (2008). Environmentally mediated coffee pest densities in relation to agroforestry management, using hierarchical partitioning analyses. *Agriculture, Ecosystems and Environment*, *125*(1–4), 120–126. https://doi.org/10.1016/j.agee.2007.12.004

Tumwebaze, S. B., & Byakagaba, P. (2016). Soil organic carbon stocks under coffee agroforestry systems and coffee monoculture in Uganda. *Agriculture, Ecosystems & Environment*, *216*, 188-193.

UCDA. (2013). Uganda Coffee Development Authority. *Uganda's Coffee Exports from 1964/65 - 2014/15*, *22*, vii–1. Retrieved from http://www.ugandacoffee.org/index.php?page&i=15

UCDA. (Factsheet). Uganda Coffee Development Authority - https://ugandacoffee.go.ug/fact-sheet

UNHS. (2016/17). Uganda National Household Survey Report., MAAIF - https://www.agriculture.go.ug/agricultural-sector-potential/

Unelius, C. R., Schiebe, C., Bohman, B., Andersson, M. N., & Schlyter, F. (2014). Non-host volatile blend optimization for forest protection against the European spruce bark beetle, *Ips typographus*. *PLoS One*, *9*(1), e85381.

Vaast, P., Bertrand, B., Perriot, J.-J., Guyot, B. and Génard, M. (2006), Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. *J. Sci. Food Agric.,* 86: 197-204. https://doi.org/10.1002/jsfa.2338

Vanderlaan, N. R., & Ginzel, M. D. (2013). The capacity of conophthorin to enhance the attraction of two *Xylosandrus* species (Coleoptera : Curculionidae : Scolytinae) to ethanol and the efficacy of verbenone as a deterrent. 391–397. https://doi.org/10.1111/afe.12026

Van Noordwijk, M. (2019). Sustainable development through trees on farms: Agroforestry in its fifth decade ed M van Noordwijk (Bogor, Indonesia: World Agroforestry (ICRAF))

Vellema, Wytse & Buritica Casanova, Alexander & González, Carolina. (2015). The effect of specialty coffee certification on household livelihood strategies and specialisation. *Food Policy.* 57. 13-25. 10.1016/j.foodpol.2015.07.003.

Wagner, S., Rigal, C., Liebig, T., Mremi, R., Hemp, A., Jones, M., … Preziosi, R. (2019). Ecosystem services and importance of common tree species in coffee-agroforestry systems: Local knowledge of small-scale farmers at Mt. Kilimanjaro, Tanzania. *Forests*, *10*(11). https://doi.org/10.3390/f10110963

Wang, N., Jassogne, L., van Asten, P. J. A., Mukasa, D., Wanyama, I., Kagezi, G., & Giller, K. E. (2015). Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda. *European Journal of Agronomy*, *63*, 1–11. https://doi.org/10.1016/j.eja.2014.11.003

Werle, C. T., Ranger, C. M., Schultz, P. B., Reding, M. E., Addesso, K. M., Oliver, J. B., & Sampson, B. J. (2019). Integrating repellent and attractant semiochemicals into a push–pull strategy for ambrosia beetles (Coleoptera: Curculionidae). *Journal of Applied Entomology*, *143*(4), 333–343. https://doi.org/10.1111/jen.12594

World Agroforestry. (ICRAF) - https://www.worldagroforestry.org/about/agroforestry

Wright, P. M., Lichtenfels, P. A., & Pursell, E. D. (1989). The structured interview: Additional studies and a meta-analysis. *Journal of occupational psychology*, *62*(3), 191-199.

Appendix 1: Farmers interview questions

I) General questions

1. Size of the coffee garden

2. Total no. of coffee plants in your garden (approx)?

3. How many years have you been dealing with coffee cultivation?

4. Is your coffee cultivation a family-run enterprise?

5. On a scale of 1 to 10, how important is coffee for the total family revenue? (1 – Not at all; 10 – Major)

6. Who takes care of the garden? (Adult male, Adult female, Labor, Children, All the above)

- Roles performed by each member (Adult male, Adult female, Labor, Children, All the above)

7. Are you a member of an association/ cooperative/ group?

8. If yes, what is the name of the association/ cooperative/ group?

9. Where do you source your coffee planting material?

10. In your perspective, what do you think are the major challenges in coffee cultivation?

On a scale of 1 to 10, please rate the following challenges with reasons

a. Pests and diseases

b. Marketability and selling

c. Proper returns

d. Extension service delivery

11. Could you please talk about the incentives you get in coffee cultivation?

12. Could you please talk about the motivation behind your coffee cultivation?

II) Knowledge on BCTB and its management practices

1. What are the different pests you see on your farm?

2. What are the common symptoms of these pests you see on your farm?

3. What are the common effects of these pest on your farm?

4. In your understanding, what is a BCTB?

5. What is your perception of the BCTB?

6. How did you get to know about this pest?

7. What are the on-farm problems that you face? (rank in order of importance)

8. Looking at the BCTB problem, how is the level of infestation now compared to previous years on your farm?

- And what do you think could be the reason?

9. If you see an increasing trend, what better could be done to improve this situation, from your perspective?

10. In your experience, what are the symptoms of a BCTB attack/ how do you find the BCTB attack?

11. What happens to the tree that is infested?

12. How much quantity of beans do you lose in your final harvest from the BCTB attack?

13. What time of the year/ season do you find the incidence of BCTB more?

And why?

14. What are the on-farm management practices you perform to control BCTB?

15. Why do you think these practices are important?

16. What spacing did you follow when planting coffee and why?

17. What do you do with the infested branches?

18. Do you do any other special practices for the BCTB?

19. In your thinking, what could be the reason for the incidence of BCTB on your farm?

20. For how many years have you had BCTB on your farm?

21. What types of intercrops do you have?

- Intercrops

- Shade trees

22. What is the reason for planting an intercrop, from your perspective?

23. What is the reason for planting shade trees, from your perspective?

24. What spacing do you follow?

25. Is it good to have an intercrop in your garden?

- Why?

26. From your perspective, how does the presence of an intercrop influence the pest?

27. Which part of the crop does it affect the most?

- Lower, Middle, Upper

- Young/ Mature shoots

28. Which part of the field do you see more infestations?

- more in the middle

- more in the edges

- don’t know

Why?

29. Infestation level of the insect on shaded coffee vs non-shaded coffee?

- More on shaded coffee

- More on non-shaded coffee

- Almost equal on both

- Not sure

Why?

30. Have you noted any predatory activity on the BCTB?

31. Who do you get the guidance from?

- Extension officers

- Researchers

- Coop members

- Parents

- Farmer friends

- Own knowledge

- Others (please mention) (we were the first people)

32. Do you get the required information you need? (Yes/No)

33. How useful/ valuable do you think the information is to your farm's improved production? (on a scale of 1 – 10)

34. What aspects do you think need to improve/ change when it comes to extension services/ advice?

35. On a scale of 1 – 10, how much would you rate yourself in welcoming new ideas on your farm?

36. Based on your understanding, what are the positives of your coffee system?

37. Based on your understanding, what are the limitations of your coffee system?

38. In addition to these, do you need any information regarding the pest?

Appendix 2: Online survey questions

1) Please select you job post

2) What roles do you perform as an officer/scientist? (you can mention more than one activity)

3) What is the most important crop in your area? (production-wise)

4) What is the most important crop in your area? (revenue-wise)

5) Number of coffee farms in your district/ area?

6) The average size of coffee farms? (in acres)

7) Type of coffee grown?

8) How many farmers do you give advice to/ come under your supervision?

9) On average, how do the farmers respond to your advice/supervision?

10) How much would you say is the rate of adoption of the practices by farmers? (Out of 10)

11) In your opinion, what needs to be done for improvement from their side?

12) What are the often heard questions/ complaints, etc. with regards to coffee? (it could be more than one)

13) How often do you visit each farmer field for advice/ supervision?

14) In your perspective, what needs to be done to improve the extension from your side? (if any)

15) In your opinion, what are the common pests and diseases of coffee in terms of incidence/ spread?

16) In your opinion, what are the common pests and diseases of coffee in terms of economic importance?

17) Are there any districts/ regions that are more severely affected?

18) What is your perception of the BCTB?

19) Would you say BCTB is the major pest? (Yes/ No)

20) If yes, could you elaborate on this? (for eg. possible reasons in your opinion, yield/ quantity loss in %, etc.)

21) If not, which other pests are more important and the possible reasons behind this?

22) What are the symptoms of BCTB/ how do you find the BCTB attack?

23) When did you come to know about BCTB and its spread in Uganda?

24) How do you think the BCTB spreads from region to region?

25) Looking at the BCTB problem, how is the level of infestation now compared to previous years? (Very much reduced/ Reduced/Almost the same/ Increased/ Very much increased)

26) And why?

27) Are you expecting any change in this trend in the near future? (Yes/ No)

28) If yes, could you describe on what you are expecting?

29) What time of the year/ season (month) do you find its incidence more and why?

30) Which stage of the insect causes damage on the trees?

31) How does the government rate the impact of the BCTB on coffee production? (Out of 10)

32) Are there any government directives regarding BCTB control? (Yes/ No/ May be, not sure)

33) If yes, could you tell more?

34) What IPM practices do you suggest to the farmers against the coffee pests (BCTB inclusive)?

35) Are there any management practices singled out for BCTB specially? (Yes/ Maybe/ No)

36) Could you mention some, if yes

36) What is the recommended spacing in coffee gardens? (Between coffee)

37) What is the recommended spacing in coffee gardens? (Between coffee and intercrop)

38) What is the recommended spacing in coffee gardens? (Between the intercrop)

39) What is the recommended spacing in coffee gardens? (Between coffee and shade trees)

40) Why do you think is spacing important? (you can mention more than one)

41) Are there any trees/ intercrops that could act as a host for BCTB? (Yes/Maybe, not sure/ No)

42) If yes, specify the trees

43) Could you please describe why it acts as a host?

44) What are the recommended intercrops with coffee?

45) What are the reasons for this selection?

46) What is the infestation level of the insect on shaded coffee vs non-shaded coffee? (More on shaded vs non-shaded vs almost the same)

47) What is the reason behind this variation in the infestation levels?

48) Are there any crops/trees which can act as a repellent plant for the BCTB? (Yes/ Maybe, not sure/ No)

49) If yes, specify the trees

50) Could you please describe what mechanism makes it repellent?

51) Have you noted any predatory activity on the BCTB? (other insects, birds, etc.)

52) Has there been any research work done on the BCTB in Uganda? (Yes/ Maybe/ No)

53) If yes, in what way is it beneficial to the farmers?

54) What is the rate of implementation of such works on farmer fields? (Out of 10)

Appendix 3: Face-to-face interviews with answers

Farmer list

1. James Kadhumbula
2. Michael Wambi
3. Suzan
4. Balwane Fred
5. Waishua David
6. Owula
7. Kiirya John
8. Mwase Mustafa
9. Karim Kibenge
10. Simon Chamawa
11. Fred Tibakula

Table 3.

I) General questions

1. Size of the coffee garden

Size of the garden	Number of farmers
1 ac	1
1.5 ac	1
2 ac	3

2.5 ac	1
3 ac	1
4 ac	2
5 ac	1
6 ac	1

Table 4.

2. Total no. of coffee plants in your garden (approx)?

Range	Number of farmers
0 – 200	-
200 – 400	-
400 – 600	2
600 – 800	1
800 – 1000	2

1000 - 2000	6

Table 5.

3. How many years have you been dealing with coffee cultivation?

Year range	Number of farmers
1 – 10	2
11 – 20	3
21 – 30	2
31 – 40	3
41 – 50	1

Table 6.

4. Is your coffee cultivation a family-run enterprise?

Farmers	Yes / No	Comments
1.	Y	But, partly. Oct-Jan harvest time, other months not

2.	Y	A teacher by profession; farming is supplementary; Coffee is the main crop
3.	N	Rearing animals is the family-run enterprise + Maize is the main crop Coffee is a new crop and only has one harvest/ year
4.	Y	Coffee is predominant but also has maize
5.	Y	Biggest cash crop; very good source of income
6.	N	Currently not ; but he believes coffee will become his main source of income with time
7.	Y	
8.	Y	Main enterprise but he also has beans, banana, cassava, maize
9.	Y	
10.	Y	
11.	N	Concentrates more on other cash crops since middlemen dealing with coffee are very exploitive.

Table 7.

5. On a scale of 1 to 10, how important is coffee for the total family revenue?

1 – Not at all; 10 – Major

Farmers	Scale	Comments
1.	10	Only one harvest/ year but gets a huge amount of money.
2.	4	-
3.	4	-
4.	5	He also has maize which gives him additional revenue. Coffee is not the only source.
5.	10	-
6.	4	-
7.	6	-
8.	5	-
9.	10	-
10.	10	-
11.	3	-

Table 8.

6. Who takes care of the garden?

Adult male	1,2,4,5,6,7,8,9,10,11
Adult female	1,3
Labour	-
Children	-
All the above	-

Table 9.

Roles performed

Person	Roles performed
Adult male	Picking coffee beans + other harvest (1, 5, 7, 9, 10) drying beans (1, 5, 7, 9) giving advice to children (1) cut the twigs (2) spraying (2, 4) remove dead twigs (2, 6) pruning (4, 5, 6, 7, 8, 9, 10, 11) digging (4) weeding (6, 7, 8, 9, 10, 11)

	marketing (7) gap filling (10)
Adult female	Cleaning the field (1) Picking beans + harvesting (1, 3, 6, 7, 8, 9) Helping (1) Weeding (2, 5, 6, 7, 8, 9, 10, 11) Digging (3, 4, 7) Pruning (3) Drying (7) Intercropping (10)
Labour	When needed (1,2) Weeding (2)
Children	Help in picking (1, 3) Weeding (2, 6, 7, 8, 10) Ploughing (2) Pruning (3, 6, 11) Digging (3, 5) Help during holidays (4) Harvesting (5, 6, 7, 8, 9) Spraying (11)
All the above	

Table 10.

7. Are you a member of an association/ cooperative/ group?

Farmers	Y / N	Comments
1.	N	Was part of a coffee marketing board, currently not.
2.	N	-
3.	N	-
4.	N	-
5.	N	-
6.	N	-
7.	N	-
8.	N	-
9.	N	-
10.	N	-
11.	N	-

Table 11.

8. If yes, what is the name of the association/ cooperative/ group?

---

9. Where do you source your coffee planting material?

Source	Number of farmers
Local nurseries	
Own seedlings (falling beans, germinating trees, own nursery beds)	1,2,3,4,5,8,9,10,11
Cooperative	
Extension agents (from the govt)	6
Other (please mention) (farmer friends)	2,6,7

Table 12.

Own seedlings = 9; Ext. agents = 1; Other = 3

10. In your perspective, what do you think are the major challenges in coffee cultivation?

Challenges	Farmers	Total
Dry season, changing weather patterns	1,3,4	3

Affordability – chemicals, tarpaulin, tools and equipment	1,4,7,8,10	5
Not able to plant shade trees	1	1
Pests (termites, black ants, brown ants, aphids, ones which affect the seeds, pest which dries the tree/put holes in the twig (6 farmers mentioned this here),	1,2,3,4,5,6,7,8,9,10,11	11
Marketing , unstable prices	1,7,10	3
Diseases (that dry the plant itself, wilt	2,3,5,6,9	5
Hard to maintain (on-farm management)	3	1
Soil infertility	3	1
Ageing- not very active as before	5	1
Thieves (force him to harvest when the beans are not ready)	5	1
Floor drying – lose bean quality	8	1
Lack of advice from technical people	11	1

Table 13.

On a scale of 1 to 10, please rate the following challenges

a. Pests and diseases

Farmers	Scale	Comments
1.	9	A very big problem
2.	8	Major challenge
3.	10	Reduction in yield. Major problem
4.	4	Not a big problem because there will be no plantations around at all. manageable
5.	10	Drying totally destroys the trees
6.	10	Causes a decline in coffee production
7.	8	He did not expect this and failed to reach his production goal
8.	8	It almost wipes away the entire plantation
9.	9	When pest attacks, it destroys his plants and his job
10.	4	He does regular weeding & pruning. He thinks this is the reason for not having a big P&D problem

11.	10	Reduces the yield

Table 14.

b. Marketability and selling

Farmers	Scale	Comments
1.	8	
2.	5	He sells his coffee to the local buyers. Not a very big problem
3.	10	No proper market at all. Price of coffee is very unstable
4.	2	Since it is a cash crop, people look for it and not the other way. Not a problem
5.	6	
6.	7	The govt has not given a std price. So, the middlemen exploit them
7.	8	No std price; middlemen exploitation
8.	7	No std price; middlemen exploitation
9.	5	Still on demand

10.	10	No std price; middlemen exploitation
11.	9	No std price

Table 15.

c. Proper returns

Farmers	Scale	Comments
1.	7	
2.	3	This is a big challenge but I manage somehow
3.	5	Because of P&D, the production gets very low and hence the return also
4.	4	Not very stable returns. Because of pest problem
5.	6	
6.	5	Because of P&D, the production and income are reduced
7.	4	The pest has not reached its peak, so he gets okay returns
8.	9	Because of pest

9.	7	Because of pest
10.	1	Coffee gives money. He somehow finds a way to sell it. It is hardwork
11.	7	Because of P&D

Table 16.

d. Extension service delivery

Farmers	Scale	Comments
1.	10	It takes ages to see AO. They give failed promises. Not useful at all
2.	10	The officers are not playing their roles these days
3.	10	No service at all. Doesn’t know who the AO is
4.	10	The AO being is neighbor, he has never seen him at his field
5.	10	
6.	4	The officers sometimes come and help in form of advice; they provided seedlings and tarpaulin
7.	10	No service at all

8.	10	Not sure if an officer exists even; no service at all (we are the first)
9.	10	No service at all
10.	10	No service at all
11.	10	No service at all

Table 17.

11. Could you please talk about the incentives you get in coffee cultivation?

Farmers	Incentives	Comments
1.	Nothing	He doesn't even know who the AO is
2.	Nothing	I am an independent farmer
3.	Nothing	
4.	Nothing	Buys his own tools and equipment
5.	Gets advice from the AO	
6.	Tarpaulin, secateurs (discouraged the use of paanga), seedlings	

7.	Nothing	
8.	Nothing	
9.	Nothing	
10.	Nothing	
11.	Nothing	

Table 18.

12. Could you please talk about the motivation behind your coffee cultivation?

Farmers	Motivations
1.	Cash crop, he gets money for food, to buy animals, etc
2.	Learnt about coffee production; no problem of rodents; cash crop; firewood
3.	High cash crop; perennial
4.	Cash crop; beautifies the land; firewood (fuel); dropping leaves become manure
5.	Cash crop (gives money in bulk); perennial crop; supports his family

6.	Perennial crop; to pay school fees; sell in bulk and get bulk amount
7.	To pay school fees; take care of family
8.	To pay school fees; supports household activity; health expense
9.	Main source of income; dries the beans and powders it for tea (African tea)
10.	Cash crop; family basic needs and medical expenses
11.	cash crop; helps him solve some problem

Table 19.

II) Knowledge on BCTB and its management practices

1. What are the different pests you see on your farm?

Farmers	Pests	Comments
1.	Wilt, BCTB, black ants, wasps	
2.	BCTB, black ants, brown ants	
3.	Brown ants, wasps, termites, rat	

4.	Brown ants, black ants, pest that dries the twigs	
5.	Insects that dry the twigs, wilt, brown ants, black ants, termites	
6.	The pest making holes and drying the twigs, the pes forming nest and causing blackening of leaves, brown ants, pest producing ash on the beans causing low quality	
7.	Drying the twigs, brown ants, pest that causes green and yellowing of leaves, pest that causes drop of mature beans	
8.	Majorly the pest that dries the twig	
9.	Brown ants, black ants, wasps, birds, pest that make holes, wilt	
10.	Termites, pest causing yellowing of leaves and drying, black ants	
11.	Termites, black ants, brown ants, pest that dries the twigs/ trees	

Table 20.

2. What are the common symptoms of these pests you see on your farm?

Farmers	Symptoms
1.	Leaves turning yellow; bean dropping and low quality of beans
2.	Blackening of branches; tunnel in the branches; drying; seed blackening; leaf folding
3.	Ants make nest on the tree; termite hills; changing colour of leaves; tree drying up
4.	Twigs turning yellowish; entire tree drying
5.	Green coffee plantation turning yellowish; dropping of beans
6.	Leaves and beans turn yellowish and burnt and then drop
7.	Drying of entire tree; yellowing and shedding of leaves
8.	Twigs turn yellowish and fall off
9.	Twigs turn yellowish and fall off
10.	Half ready beans and half immature beans (green) during harvest
11.	Ants make nests on the leaves; holes in the twigs; blackening of beans

Table 21.

3. What are the common effects of these pest on your farm?

Farmers	Symptoms
1.	Low economic returns
2.	Low yields = low income; tree gets dried up
3.	Loss in production; ants bite and cause trouble during harvest; also wasps
4.	The plantation cared for this long will be gone completely; low income
5.	Very low production
6.	Very low production and income
7.	No production of healthy beans; low standard of coffee; loss of motivation
8.	Does not get the expected outcome
9.	Decline in production
10.	Decline in production
11.	Decline in production

Table 22.

4. In your understanding, what is a BCTB?

Farmers	Answer
1.	A problematic insect; it can be found in the twigs with a hole
2.	An insect which destroys young branches on coffee; very dangerous pest
3.	No idea what the insect is
4.	When he finds a dried twigs and breaks it, he sees eggs inside
5.	Checked the dried twigs and found out the presence of white coloured eggs
6.	The pest that makes holes and that dries the twigs
7.	A black-colored insect that makes holes
8.	The pest that makes holes and that dries the twigs
9.	Black twigs with holes, when touched, falls down; black-colored insect inside
10.	Twigs look different from the healthy ones; holes present
11.	Turns the twigs into black colour and also make holes

Table 23.

5. What is your perception of the BCTB?

Farmers	Perception
1.	It is a big problem and science should do something about it soon. The economic returs are declining
2.	A very dangerous pest. It destroys the whole plant; reduced yield; management is also very complicated
3.	Even though I see it, I don't have anything to do about it. No knowledge on its management
4.	Scientists should wake up and come to rescue the situation, otherwise everything will be gone
5.	Tried spraying but did not work. This pest does not die at all
6.	Nothing much to say but the govt can bring some chemical to destroy this pest otherwise it will become worse
7.	Very dangerous; govt should come up with a chemical to control this pest
8.	Better to find a solution sooner than later
9.	If no solution found, with time, there will be no coffee plants
10.	Very bad. Declines the yield; scientists with pesticide to kill the insect

11.	Wants to cut the whole tree but feels it would be a loss for him. This insect is making him wonder what to do

Table 24.

6. How did you get to know about this pest?

Farmers	Answer
1.	-
2.	Came to know when most of his coffee plants were dry, then tried to check the twigs and found out this insect
3.	In the field; 5 years back
4.	Farmer friend
5.	Realized a lot of twigs drying which lead to its low production
6.	Picked and cut a dried twig and realized the presence of a black-colored insect
7.	Farmer friends
8.	Checked a dried twig and found a black-colored insect
9.	Saw an insect entering the hole; found many when tried to break

10.	Learnt about this while pruning
11.	Farmer friend

Table 25.

7. What are the on-farm problems that you face? (rank in order of importance)

Farmers	Problems
1.	Lack of tools and equipment for on-farm operations Irrigation system, lack of water Transportation of coffee beans to the marketing place
2.	Pests and diseases Slashing and keeping the field weed-free all the time
3.	Unknown pest this is killing the plantation Brown ants Termite hills Neighbors rearing animals in her area
4.	Drought Problem of getting seedlings Small land

	Lack of affordability to get a new, larger area. (feels he could do better)
5.	The pest that dries the twig The disease that dries the plant completely Black ants Termites
6.	Pests Low coffee yield
7.	Lack of access to chemicals for spraying Big size of land makes work hectic Lack of access to tarpaulin
8.	Pests Lack of tools to take care of the garden Lack of tarpaulin for drying
9.	Weeding during rainy season Pests (BCTB) Thieves
10.	Lack of access and money to get pesticides
11.	Lack of advice

	Lack of access to tools and equipment

Table 26.

8. Looking at the BCTB problem, how is the level of infestation now compared to previous years on your farm?

Level of infestation	Farmers
Very much reduced	-
Reduced	2, 10
Almost the same	-
Increased	3, 7, 8, 9
Very much increased	1, 4, 5, 6, 11

Table 27.

And what do you think could be the reason?

Farmers	Reason
1.	Because the yield has become very low these days; 5 bags down to 2 bags

2.	Realized it was more under shade and with proper management of shade, the infestation got reduced
3.	Because of more trees drying up
4.	Not sure, it could be the weather pattern
5.	People are destroying nature (deforestation) and allowing the pest to come to coffee gardens
6.	The coffee got from the government is still young and the pest enjoys young ones
7.	There are no specific management practices to control the pest
8.	Because there is no solution to stop this pest
9.	Increased because of not applying chemicals
10.	Practicing regular pruning could be the reason
11.	No way to stop it

Table 28.

9. If you see an increasing trend, what better could be done to improve this situation, from your perspective?

Farmers	Comments
1.	Bringing in new resistant trees Chemicals to spray the pests
2.	A suitable chemical to suppress the pest population
3.	Help from government and officers
4.	Scientists should come up with new pesticides to kill this pests
5.	Researchers and professors should work hand in hand in developing a chemical and test
6.	Can be rescued by the government by doing research
7.	Government should act fast and try to find solutions
8.	Specific pesticide is needed, otherwise all the trees will be affected
9.	Support in form of money/ pesticide can be of help
10.	If the neighboring farmers also do pruning, the situation could get better
11.	Technical advice from scientists and AO, the situation could be improved

Table 29.

10. In your experience, what are the symptoms of a BCTB attack/ how do you find the BCTB attack?

Farmers	Symptoms
1.	Yellowing of leaves Dropping of coffee beans Half green & half dried up twigs
2.	Dried up foliage, especially the young branches
3.	Drying of twigs
4.	The blackening and cracking of the twig
5.	Black and dried twigs with white eggs inside
6.	A hole in the twig Yellowing of leaves Dropping of leaves
7.	Yellowing of leaves Slight bending of branch and will break it
8.	Identifies the twigs by drying

9.	Dried twigs
10.	Twigs and leaves will turn yellowish and no longer look healthy
11.	Yellowing of leaves Twigs turning black Holes in the twig

Table 30.

11. What happens to the tree that is infested?

Farmers	Infected tree
1.	Yellowing of leaves – dropping of leaves – blackening of beans – bean dropping – finally drying
2.	It gets dried up slowly, beginning from the twigs up to the stem and eventually the whole tree dries
3.	Dries up completely
4.	Low quality beans; tree dries completely
5.	Dries up completely
6.	Dries up completely

7.	Dries up completely
8.	Dries up completely
9.	Dries up completely
10.	Leaves will shed and tree dries
11.	Dries up completely

Table 31.

12. How much quantity of beans do you lose in your final harvest from the BCTB attack?

Farmers	Yield loss
1.	~80kg loss in one season from ~400kg yield
2.	Have not been noting this really these days with lack of time but I think it should be normal with proper management
3.	300kg loss (1000kg harvest)
4.	20% of harvest loss every season (10 bags = 2 bags loss)
5.	2000kg/season but only gets 1200kg (800kg loss/ season)

6.	Usually 800kg/ season but now loses 400kg/ season (50% loss)
7.	Usually 2000kg/ season but now only 1500kg/ season (~500kg/ season)
8.	1000kg/ season harvest (loses 300kg/ season)
9.	Usually 1000kg/ season but now only 300kg/ season (700kg/season loss)
10.	Loses ~40kg/ season
11.	1000kg/ season (loses ~400kg/ season)

Table 32.

13. What time of the year/ season do you find the incidence of BCTB more? And why?

Farmers	Months	Why?
1.	Jan, Feb, Mar	Lack of sufficient water during dry seasons, which makes the tree vulnerable
2.	April, May, June	Lots of twigs in the rainy season
3.	July, Aug, Oct	Because the trees will be flowering and the pest will have enough food
4.	July, Aug	Not sure of the reason

5.	May, June, July	Rainy season
6.	April, May, June	Tree produces beans at this time
7.	Feb, Mar, April	This is the time when it lays a lot of eggs
8.	June	Very dry season
9.	Oct, Nov, Dec	Could be because of the harvest season
10.	Jul, Aug	Starts to see the blackened seeds
11.	April, July	Flowering time

Table 33.

14. What are the on-farm management practices you perform to control BCTB?

Practices	Farmers
Pruning	1,8
Firewood	1,9
Cut the twigs	2,5,8,11

Cut and Burn	3, 4, 6, 7, 10
Uproot the tree	5, 10, 11
Pesticide	6

Table 34.

15. Why do you think these practices are important?

Farmers	Why ?
1.	To kill the pest and avoid spread
2.	To allow the tree to grow healthy
3.	Reduce infestation levels
4.	To reduce the spread
5.	To reduce the spread
6.	-
7.	Cut the twigs because it is like a poison to the rest of the tree
8.	To reduce the spread

9.	-
10.	To avoid the spread
11.	To eliminate the pest completely and use as firewood

Table 35.

16. What spacing did you follow when planting coffee and why?

Spacing	Farmers
6ft x 6ft	1
10ft x 10ft	2,3,4,5,6,7,8,9,10,11
Random & gap filling	3

Table 36.

17. What do you do with the infested branches?

	Farmers
Cut & burn	1,3,4,5,6,7,10,11

Cut the twigs only	2
As fuel	8,9

Table 37.

18. Do you do any other special practices for the BCTB?

Y / N	Farmers
Y	
N	1,2,3,4,5,6,7,8,9,10,11

Table 38.

19. In your thinking, what could be the reason for the incidence of BCTB on your farm?

Farmers	Reason
1.	No idea
2.	No idea
3.	Cutting trees around made the pest come to his coffee

4.	Could be a natural thing but not sure of the reason
5.	Deforestation
6.	Coffee given by the government must have had the pest already
7.	Deforestation
8.	Not sure
9.	Not sure
10.	Changes in weather pattern
11.	Not sure, may be through air

Table 39.

20. For how many years have you had BCTB on your farm?

Farmers	Years
1.	5

2.	20 - 22
3.	5
4.	4
5.	20
6.	4
7.	5
8.	5
9.	15
10.	3
11.	15

Table 40.

21. What types of intercrops do you have?

Farmers	Crops	Shade trees

1.	Banana, cassava	Musizi, mutumba
2.	Beans, banana, maize, cassava	Muwule, musizi, mugairei, musita, jackfruit
3.	Banana, cassava	Mango, jackfruit, mugairei, musizi
4.	Beans, cassava, banana	Musizi, mugairei, muwule
5.	Banana	Mango, jackfruit, mukako, mugairei, musizi, orange
6.	Banana	Mugairei, musizi
7.	Cassava, banana, yams	Musizi, mugairei, mukoko
8.	Banana, yams, beans	Musizi, jackfruit, orange
9.	Banana	Orange, musizi, mutuba
10.	Banana, ground nuts, beans, cassava, sweet potato, maize	Mugairei, musizi, mango, jackfruit, mukoko, muwule
11.	Banana, beans	Orange, mugairei, muyembe, muwule

Table 41.

22. What is the reason for planting an intercrop, from your perspective?

Reason	Farmers
Motivation to dig the field + on-farm activities	1, 3, 11,
To get both money and food	10, 4, 8
To get food	1, 5, 9
To add nutrients to the soil; to control erosion	2
To make full use of the land	6
To get shade	7

Table 42.

23. What is the reason for planting shade trees, from your perspective?

Reason	Farmers
For shade	1, 2, 3, 4, 5, 6, 7, 8, 9, 11

Trees help in getting more rainfall	10
To control weeds	2
Leaves serve as manure	3, 7
Firewood	4
To prevent flower dropping	5

Table 43.

24. What spacing do you follow? (RP = Random Planting)

Farmers	b/w coffee and intercrop	b/w coffee and shade tree
1.	In the middle of 4 coffee trees	20ft
2.	At least a meter	RP
3.	RP	RP
4.	RP	RP
5.	In the middle of 4 coffee trees	50ft

6.	RP	Every 5m
7.	RP	RP
8.	RP	RP
9.	RP	10ft
10.	RP	RP
11.	RP	RP

Table 44.

25. Is it good to have an intercrop in your garden?

	Farmers
Very good	1, 3, 5, 6, 7, 9
Good	2, 4, 8, 11
Somewhat okay	-
Not good	10

Not not good	-

Table 45.

Why?

Farmers	Reason
1.	Will provide shade and manure after harvest
2.	Add nutrients; control weeds
3.	For food; 2 benefits
4.	Food and income
5.	Food and income
6.	Food and income
7.	Motivates him to do on-farm practices
8.	Source of income
9.	Food and income

10.	There will be competition. Maize in particular
11.	2 in 1, will get both money and food

Table 46.

26. From your perspective, how does the presence of an intercrop influence the pest?

Farmers	Reason
1.	The insect can hide in banana plantations for shade
2.	By providing favorable conditions for the pest
3.	Don’t know
4.	They do not help the pest at all
5.	It is of no influence
6.	No influence
7.	Acts as shade and makes environment cool
8.	Not sure

9.	No influence because this pest feeds only on coffee
10.	Not sure
11.	Not sure

Table 47.

27. Which part of the crop does it affect the most?

Farmers	Lower/ middle/ upper	Young shoots/ mature shoots
1.	U	Y
2.	U	Y
3.	U	Y
4.	M	M
5.	M	Y
6.	M	Y
7.	M	Y

8.	L	Y
9.	M	Y
10.	L	Y
11.	L	M

Table 48.

Part affected the most	Farmers
Lower	3
Middle	5
Upper	3

Table 49.

28. Which part of the field do you see more infestations?

	Farmers
More in the middle	1, 2, 4, 5, 6, 7, 8, 9, 11

More in the edges	10
Don’t know	3

Table 50.

Why?

Farmers	Reason
1.	Air blows it and brings it to the center
2.	More shade in the middle; randomly spread in some cases
3.	Don’t know
4.	Mature and healthy coffee beans in the middle
5.	There is a lot of shade and the pest like shade
6.	No explanation
7.	Better yielding plants in the center
8.	No reason

9.	Good and healthy trees
10.	Neighbors do not do regular pruning
11.	Not sure

Table 51.

29. Infestation level of the insect on shaded coffee vs non-shaded coffee?

Infestation	Farmers
More on shaded coffee	2, 5, 6, 9, 10
More on non-shaded coffee	1, 4, 7, 11
Almost equal on both	-
Not sure	3, 8

Table 52.

Why?

Farmers	Reason

1.	No place to hide for the insect, so only attacks coffee
2.	Good and favorable condition
3.	-
4.	It gets direct sunlight and helps the pest to survive
5.	Likes to live in shade and lay eggs under shade
6.	Perfect place for the pest to survive
7.	No reason
8.	-
9.	It is always cool
10.	No direct sunlight
11.	Easy for the pest to enter the trees

Table 53.

30. Have you noted any predatory activity on the BCTB?

Reason	Farmers
Yes	-
No	2, 3, 4, 5, 6, 7, 8, 9, 10, 11
He thinks he might be the predator as he breaks the twig	1

Table 54.

31. Who do you get the guidance from?

Guidance	Farmers
Extension officers	5, 6
Researchers	-
Coop members	-
Parents	10
Farmer friends	7, 11
Own knowledge	2, 4, 8, 9

Others (please mention) (we were the first people)	3

Table 55.

32. Do you get the required information you need?

Y/N	Farmers
Yes	5 (for now), 6
No	1, 2, 3, 4, 7, 8, 10, 11

Table 56.

33. How useful/ valuable do you think the information is to your farm's improved production? (on a scale of 1 – 10)

Farmers	Scale
1.	10
2.	1
3.	10
4.	1

5.	6
6.	6
7.	1
8.	-
9.	-
10.	3
11.	6

Table 57.

34. What aspects do you think need to improve/ change when it comes to extension services/ advice?

Farmers	Change
1.	AO should take time to check Open the stores again Have a separate office for coffee
2.	AO- more vigilant and active and do their roles

	"Wake up and do serious business"
3.	AO should leave office and come to the field
4.	AO should leave office and come to the field
5.	Good service; maybe they should take new courses
6.	Officers should inform farmers about the pests and also try to research new solutions
7.	AO should leave office and come to the field Support from NGOs through AO with pesticides
8.	AO should leave office and come to the field
9.	AO should leave office and come to the field; remind them why they are employed
10.	A common nursery to get seedlings and also share knowledge; supervised by AO/Government
11.	AO should leave office and come to the field

Table 58.

35. On a scale of 1 – 10, how much would you rate yourself in welcoming new ideas on your farm?

Farmers	Scale
1.	10
2.	7
3.	10
4.	10
5.	10
6.	10
7.	10
8.	10
9.	10
10.	10
11.	10

Table 59.

36. Based on your understanding, what are the positives of your coffee system?

Farmers	Positives
1.	Proper digging Implementing new strategies Local nursery Gap filling
2.	Weeding Tilling Cut and burn Apply manure
3.	Digging Pruning
4.	Pruning Mulching Weeding
5.	Weeding Regular pruning Trying to fight the pest
6.	Weeding ; pruning

7.	Weeding Digging trenches Pruning Harvest only red coloured beans
8.	W; P
9.	W; P; Look for infestations
10.	W; planting shade trees
11.	W; P

Table 60.

37. Based on your understanding, what are the limitations of your coffee system?

Farmers	Limitations
1.	No access to tools and equipment No access to tarpaulin
2.	No spraying with chemicals No proper recommendation for this
3.	Lack of funds to buy new tools

4.	Mostly dependent on the adult male Changing weather patterns
5.	Lack of money Personal health problems
6.	No limitations he feels
7.	Little knowledge about the pest
8.	Lack of tools and equipment & tarpaulin Reduced market
9.	Lack of tools and equipment Drought
10.	Lack of access to chemicals
11.	Lacking proper advice

Table 61.

38. In addition to these, do you need any information regarding the pest?

Farmers	Information

1.	Yes, info on new resistant varieties
2.	Yes, type of chemical used to control this pest Good coffee management practices
3.	Yes, knowledge on how to control the pest Any chemical available to spray?
4.	Yes
5.	Yes, info on how to destroy this pest
6.	Yes
7.	Yes, any chemical to control this pest?
8.	Yes, info on how to stop it?
9.	Yes, more info on pesticide
10.	Yes, info on how to stop it? Also on pesticides
11.	Yes, info on how to stop it?

Table 62.

Appendix 4: Online surveys of officials with answers

1) Please select you job post

1. Extension officer
2. Extension officer
3. Extension officer
4. PhD fellow
5. Scientist
6. Scientist
7. Extension officer
8. Extension officer
9. Extension officer
10. Production officer

Table 63.

2) What roles do you perform as an officer/scientist? (you can mention more than one activity)

1.	I train farmers in agronomic practices and thereafter advance seed to farmers that successfully finish trainings. I continuously monitor the farmers until harvest of their crops and help them secure market to get income from produce.
2.	Identification of farmers of selected crop enterprises, training farmers on proper soil and water management and conservation practices, crop agronomic practices and post harvest handling of different crops(annual and perennial food and cash crops)
3.	I work with Uganda Coffee Development Authority a Regional coffee extension officer and i coordinate coffee activities in the district including coffee extension, production and distribution of coffee planting materials, coffee pest and disease surveillance and management and other coffee production enhancement programs
4.	Entomology
5.	IPM research, technology dissemination
6.	Conducting research for development on coffee and cocoa pests
7.	-
8.	-

9.	- Regulation of farmers and farmers' organizations. - Training of farmer groups in Agribusiness through the FFS approach. - Conducting public awareness meetings on major crop pests and diseases. - Farm visits for technical guidance and on-farm demonstrat
10.	-

Table 64.

3) What is the most important crop in your area? (production-wise)

1.	Maize
2.	Based on the project target area; millet, grain amaranths, soy bean, maize, orange flesh sweet potatoes, cassava, vegetables. But for the case of income and food security, we introduced cash crops like cocoa and coffee to provide alternative source of revenue for to buy food and other livelihood needs.
3.	Coffee
4.	Banana
5.	Coffee
6.	Bananas

7.	Coffee (robusta)
8.	CASSAVA
9.	Maize
10.	MAIZE

Table 65.

4) What is the most important crop in your area? (revenue-wise)

1.	Tomatoes
2.	Coffee
3.	Coffee
4.	Banana
5.	Coffee
6.	Coffee
7.	Robusta coffee

8.	COFFEE
9.	Coffee
10.	COFFEE

Table 66.

5) Number of coffee farms in your district/ area?

1.	If >500, please mention an approximate range
2.	400 - 600
3.	-
4.	200 - 400
5.	10000-50000
6.	2000-6000
7.	If >1000, please mention an approximate range below
8.	800 - 1000

9.	800 - 1000
10.	-

Table 67.

6) The average size of coffee farms? (in acres)

1.	0 - 2
2.	-
3.	0 - 2
4.	-
5.	0 - 2
6.	-
7.	0 - 2
8.	0 - 2
9.	0 - 2

10.	0 - 2

Table 68.

7) Type of coffee grown?

1.	Coffea robusta
2.	Coffea robusta
3.	Coffea robusta
4.	Arabica-90%, Robusta-10%
5.	Coffea robusta
6.	Coffea robusta
7.	Coffea robusta
8.	Coffea robusta
9.	Coffea robusta
10.	Coffea robusta

Table 69.

8) How many farmers do you give advice to/ come under your supervision?

1.	200
2.	20 farmers monthly
3.	On average 150 in a month, although recently the numbers have been much less (about 50 per month) due to due to restrictions on movement and gatherings due to Covid 19
4.	50
5.	1500000
6.	>1000
7.	Over 10,000farmers
8.	600 farmers both in trainings and farm visits.
9.	750
10.	85000 farming households (different enterprises) in all 14 rural sub countries.

Table 70.

9) On average, how do the farmers respond to your advice/supervision?

1.	Positive (welcoming new ideas, motivated to see a change)
2.	Positive (welcoming new ideas, motivated to see a change)
3.	Other (Specific comments below)
4.	Positive (welcoming new ideas, motivated to see a change)
5.	Positive (welcoming new ideas, motivated to see a change)
6.	Positive (welcoming new ideas, motivated to see a change)
7.	Positive (welcoming new ideas, motivated to see a change)
8.	Positive (welcoming new ideas, motivated to see a change)
9.	Positive (welcoming new ideas, motivated to see a change)
10.	Positive (welcoming new ideas, motivated to see a change)

Table 71.

10) How much would you say is the rate of adoption of the practices by farmers? (Out of 10)

1.	7

2.	8
3.	5
4.	3
5.	4
6.	7
7.	4
8.	6
9.	3
10.	5

Table 72.

11) In your opinion, what needs to be done for improvement from their side?

1.	-
2.	Requires pruning tools/pesticides/chemicals to manage crop canopy and pesticides/diseases

3.	Using more practical oriented extension approaches such as hands on practical trainings and establishment of demonstration sites in the farmers' communities. Most of the farmers are illiterate and may easily forget when given advice verbally, however when they learn by doing, they grasp better and don't easily forget. Also establishment of demonstration sites for new technologies or good agronomic practices helps to improve adoption as the farmers are able to see for themselves what works
4.	Should be provide with soft loans
5.	Make technologies easily accessible and affordable
6.	Strengthening extension services
7.	Increase more awareness creation with all stakeholders involved, government to give subsidies on inputs, irrigation should be promoted, government to increase the budget line in Agriculture and look at value addition to expand on local market.
8.	-
9.	-
10.	-

Table 73.

12) What are the often heard questions/ complaints, etc. with regards to coffee? (it could be more than one)

1.	1.What stage to harvest beans

	2. Why coffee beans are blackening at an early stage 3. Can I grow other trees in the coffee garden 4. What is the harvest period
2.	Poor quality of harvested beans(harvest unripe beans), lack storage and drying materials, lack of reliable market for coffee, Theft of coffee in the gardens, Middle men frustrate farmers with low prices.
3.	High prevalence of pests and disease, low prices from middle men, theft of coffee in the field in some communities causing farmers to harvest their coffee prematurely
4.	How to manage BCTB
5.	Pests and diseases, low pricing and lack of inputs
6.	Coffee pests especially black coffee twig borer (BCTB) and diseases especially red blister and coffee wilt disease (CWD)
7.	Lack of land by youths and women for coffee production. Lots of pests and diseases yet agrochemical are expensive; farmers don't get adequate extension messages; low production per unit area due to declined soil fertility.
8.	-
9.	New coffee variety lines have a shorter life span.
10.	-

Table 74.

13) How often do you visit each farmer field for advice/ supervision?

1.	Or whenever required
2.	Once a week
3.	Or whenever required
4.	Or whenever required
5.	Or whenever required
6.	Or whenever required
7.	Or whenever required
8.	Or whenever required
9.	Or whenever required
10.	Once a month

Table 75.

14) In your perspective, what needs to be done to improve the extension from your side? (if any)

1.	Train and facilitate Community based Trainers
2.	Provide more resources; funds, planting and, training materials. Empower farmers on post harvest handling and value addition
3.	Organizing farmers in groups so that it is easier to reach out to more farmers at ago, supporting more practical approaches to extension (this may require additional resources in terms of tools and equipment and other materials) for practical demonstration of good agronomic practices and new technologies
4.	Government need to increase on Research funds
5.	Proper facilitation for extension workers; make use of mobile telephone communication technology for information dissemination.
6.	Should be better facilitated
7.	Recruit more extension staff at parish level or create circles to reduce on the farmer : extension service by officers, MAAIF to regularly supervise districts. Have a specialist technical person for all the priority crops/commodities.
8.	-
9.	-
10.	-

Table 76.

15) In your opinion, what are the common pests and diseases of coffee in terms of incidence/ spread?

1.	Disease- Bacterial Wilt Pests- Twig Borer, mealy bug
2.	Coffee wilt, coffee twig borer, coffee berry, coffee leaf rust, coffee berry borer beetle, cercospora leaf spot, berry blotch
3.	The black coffee twig borer, coffee mealy bugs and red blister disease
4.	BCTB coffee mealybugs coffee berry borer coffee wilt disease coffee red blister
5.	Pests: Black coffee twig borer, coffee berry borer, stem borers, root mealybugs and tailed caterpillars; Diseases: Coffee wilt disease, coffee berry disease, coffee leaf rust and red blister disease.
6.	BCTB for pests and red blister and CWD for diseases
7.	Coffee Wilt Disease, coffee berry disease,red blister disease. Coffee twig borer pest, leaf miner, stem borer

8.	Pests include : Black coffee twig borer, Mealy bugs, Leaf miners, Termites, Stem borer but to a less extent. Diseases : Coffee wilt disease, Coffee leaf spot, Red blister disease.
9.	-
10.	-

Table 77.

16) In your opinion, what are the common pests and diseases of coffee in terms of economic importance?

1.	Twig borer
2.	Coffee Twig borer, coffee berry borer beetles, berry blotch
3.	The black coffee twig borer and coffee wilt disease
4.	BCTB Coffee berry borer Coffee wilt disease coffee red blister
5.	Pests: Black coffee twig borer, coffee berry borer, coffee stem borer and coffee root mealybugs; Diseases: Coffee wilt disease, coffee berry disease and coffee leaf rust.

6.	BCTB for pests and red blister for diseases
7.	Black coffee Twig borer, coffee Wilt disease
8.	Pests : Black coffee twig borer, Mealy bugs, Termites. Diseases : Coffee wilt disease, Red blister disease.
9.	-
10.	-

Table 78.

17) Are there any districts/ regions that are more severely affected?

1.	Yes
2.	yes: Luuka district
3.	Yes, Busoga region generally is more affected by the black coffee twig borer
4.	yes
5.	Yes - regions with more predisposing agroecological conditions

6.	Yes
7.	Almost all district are affected
8.	Kayunga district Iganga district Buyende district Mukono district
9.	Kamuli district, Masaka, Kalungu
10.	All sub countries in Kamuli are severely affected

Table 79.

18) What is your perception of the BCTB?

1.	Very destructive. It cannot be completely eliminated by spraying the coffee field so farmers are confused on how to control it effectively
2.	It's a deadly disease, that farmers have not differentiated from the rest of the pests. Extension services are urgently need to inform and find cheaper ways of addressing the diseases
3.	The BCTB is a big threat to productivity of Robusta coffee in Uganda.
4.	BCTB is a major pest of Robusta coffee in Uganda now

5.	One of most important coffee production constraint in Uganda today
6.	it is currently the most important insect pest infesting coffee, particularly Robusta coffee
7.	Needs community action and government should handle expeditiously
8.	It is very destructive and an economic pest which is hard to manage if the neighbouring farmers are not managing it.
9.	It is a notorious pest of coffee. Wide spread.
10.	Needs urgent attention

Table 80.

19) Would you say BCTB is the major pest? (Yes/ No)

1.	No
2.	Yes
3.	Yes
4.	Yes
5.	Yes

6.	Yes
7.	Yes
8.	Yes
9.	Yes
10.	Yes

Table 81.

20) If yes, could you elaborate on this? (for eg. possible reasons in your opinion, yield/ quantity loss in %, etc.)

1.	-
2.	its a key, because I planted with a farmer 72 plants of NACORI-Kituza Resistant (KR line 1 to 7)Varieties and after one year, I had 42 plants. 30 died mainly due to BCTB. I visited a farmer with 3 acres in balawoli whose garden was infested, but did not know the disease causing his plants to die.
3.	It is the most widely spread and also most difficult to manage as it spreads very fast and requires community effort in managing (as it can easily re-infest a farmers field from the neighbour's garden). It is also a bigger threat to productivity since it attacks and causes drying of the coffee primary branches which are supposed to bear the coffee beans
4.	Almost all coffee farms in the major Robusta growing regions are infested causing on average 9.6% loss per farm

5.	Causes approximately 10% loss in total annual national coffee production and export volume
6.	BCTB attacks the berry-bearing primary branches and those branches do not bear berries and thus causes directly yield loss - presently estimated at 9,6%
7.	If not handled it can cause over 40% yield loss and reduce on household income and government revenue from the exports
8.	It is a major pest in coffee now because it is hard to manage as most farmers may not be able to identify it as it enters through under side of the twig. The chemicals used are very expensive. It also has a wide host range including the shade trees farmers normally use eg Musize. It can cause a yield loss of 70% in just one year if not managed hence drying of the coffee plants.
9.	It may lead to a 40% yield reduction. It has ability to destroy twigs and coffee tree stems and consequently low productivity of coffee trees for the subsequent seasons.
10.	It can be estimated to be responsible for close to 40% loss of the yield potential.

Table 82.

21) If not, which other pests are more important and the possible reasons behind this?

1.	Mealy bug
2.	-
3.	-

4.	-
5.	-
6.	Not applicable
7.	Coffee stem borer and leaf miners
8.	N/A
9.	N/A
10.	-

Table 83.

22) What are the symptoms of BCTB/ how do you find the BCTB attack?

1.	Wilting in the coffee plants
2.	wilting and then drying of terminal leaves along the twig to the stem. Yellowing of leaves, Holes are made in the twigs and stems observed when cut or looked underside of the leaves
3.	Wilting and drying of affected twigs, small holes on the affected twigs, insect larvae or adult insect can be seen inside the affected twig when broken

4.	pinsized hole, drying/wilting of the twigs, presence of the beetles inside the hole
5.	Wilting coffee primary branches, pin-size hole at point of entry of beetle into primary branch, and splitting the affected branch reveals the broods in tunnel created by the beetle.
6.	Pin-sized characteristic hole, wilting and drying of leaves, primary branches and suckers
7.	Dieback and yellowing of leaves eventually turning black as a result of blocked xylem/phloem vessels, the berries turn black and don't fall off easily
8.	-
9.	-
10.	Drying of coffee twigs off the coffee trees and eventual drying of entire plant(s). It is highly destructive and contributing to significant losses in coffee production.

Table 84.

23) When did you come to know about BCTB and its spread in Uganda?

1.	8 years ago
2.	2016
3.	In 2015 while attending a training on coffee specific extension with Cafe Africa Uganda

4.	2011
5.	In 1993 when it first made its appearance in Uganda in Bundibugyo district, bordering Democratic Republic of Congo
6.	2011
7.	7to 8 years ago by the ministry of agriculture and research stations
8.	-
9.	In the media when MAAIF was reporting about the outbreak in 2018.
10.	The chalk has been seen around for more than 5 years now, but the extent of damage(severity) goes on increasing every year.

Table 85.

24) How do you think the BCTB spreads from region to region?

1.	Through the flying insects movements
2.	Use of same equipment and tools, Poor sanitation and hygiene
3.	The adults are capable of flying for long distances hence they can spread by flying
4.	The spread is high

5.	Through infested planting materials; relayed by alternate hosts; and by wind aided flights
6.	Flying - the adult female beetle is able to fly 200 m in a single flight and in windy conditions can make several km but can also be transmitted in infested planting materials including planting materials
7.	Presence of Host trees like musizi, makamia etc, failure to practice good agronomical skills, transportation of diseased planting material and coffee related materials
8.	It is spread by wind. It is also spread by carrying infestation coffee seedlings and coffee plant parts from one region to another.
9.	- Farmers that move alternative hosts; - Farmers that move coffee seedlings from region to region - Flight of mature BCTB from one plant field to another.
10.	Through transportation infected planting materials.

Table 86.

25) Looking at the BCTB problem, how is the level of infestation now compared to previous years? (Very much reduced/ Reduced/Almost the same/ Increased/ Very much increased)

1.	3. Almost the same
2.	4. Increased

3.	4. Increased
4.	4. Increased
5.	4. Increased
6.	4. Increased
7.	4. Increased
8.	4. Increased
9.	2. Reduced
10.	5. Very much increased

Table 87.

26) And why?

1.	Limited technical support to create awareness and control it in the community
2.	No control measures are being implemented. Farmers failure to identify the disease.
3.	It is believed that the BCTB has been in existence in Uganda for long but the pests previously were in forested areas and rarely appeared on farms. However due to the increased deforestation activities and subsequent reduction in forest cover in the

	country, the pests migrated to farm lands hence the increase in spread in coffee fields and on other host plants
4.	the number of farmers complaining about it is increasing
5.	Low adoption of management recommendations, lack of adherence to quarantine regulations.
6.	Farmers are fatigued with management - labor intensive and time-consuming and needs a community-based approach to limit re-infestation from non-managing farms
7.	Farmers assume it's felt with by use of chemical and forget the cultural methods and good husbandry practices like desuckering, prunning, stumping and avoid intercrop with host tree sheds
8.	-
9.	-
10.	There is need to handle the challenge through a community approach.

Table 88.

27) Are you expecting any change in this trend in the near future? (Yes/ No)

1.	Yes
2.	Maybe

3.	Yes
4.	Yes
5.	Yes
6.	Yes
7.	Yes
8.	Yes
9.	Yes
10.	No

Table 89.

28) If yes, could you describe on what you are expecting?

1.	We are commencing technical work with coffee farmers this year and focus will be on promoting increased yields among new and existing coffee farmers. Trainings and support to farmers on yield loss control will focus on pest elimination in coffee fields. the BCTB will be high on the priority list
2.	-

3.	The government, through Uganda coffee development authority and other development partners in the coffee sector have come up with different interventions to control and manage the twig borer in the affected regions. These interventions include sensitization of farmers on management of the pest as well as distribution of recommended pesticides to affected communities
4.	i expect it to reduce as more farmers are taking up the management practices
5.	A biological control programme developed and implemented.
6.	Unless a community-based approach for managing the pest is used
7.	By research trying to get better coffee planting material tolerant to black coffee twig borer
8.	-
9.	- Mutation may lead to evolution of resistant strains of BCTB; - Drug resistance/pesticide resistance could lead to an upsurge in the pest population.
10.	-

Table 90.

29) What time of the year/ season (month) do you find its incidence more and why?

1.	2nd Dry season (December- February)

2.	July, August, September January, February, December
3.	BCTB is more prevalent during dry periods of the year (May to July and November to February)
4.	dry seasons
5.	Most new infestation occur in June and September when both humidity and temperature are high enough to enable the female beetle to emerge to establish new colonies. However, since incidence is measured on occurrence of symptoms, this will occur in the relatively low precipitation months of July and October.
6.	Dry season - because the plant is stressed - BCTB is an ambrosia beetle and these beetles love attacking dead or stressed plant materials
7.	May to July and December to March
8.	November â€" March. - The dry weather favours their multiplication. - The crop vigour is compromised.
9.	Dry season (December -- Feb) and (July -- August) because the pest multiplies more during dry season and the crop immunity is lower.
10.	Not specific

Table 91.

30) Which stage of the insect causes damage on the trees?

1.	larvae
2.	mostly the larvae. to small extent adult
3.	Larva and adult stages
4.	Adult
5.	The adult bores into primary branch and tunnels into the pith, thus creating mechanical damage
6.	Adult
7.	The larvae stage is more devastating
8.	Larvae as the ambrosia fungi block the translocation system of the plant hence drying the twigs.
9.	
10.	Larval/Pupal stage

Table 92.

31) How does the government rate the impact of the BCTB on coffee production? (Out of 10)

1.	4
2.	8
3.	-
4.	10
5.	10
6.	7
7.	2
8.	8
9.	6
10.	7

Table 93.

32) Are there any government directives regarding BCTB control? (Yes/ No/ May be, not sure)

1.	Yes

2.	May be, not sure
3.	May be, not sure
4.	No
5.	Yes
6.	Yes
7.	Yes
8.	Yes
9.	No
10.	Yes

Table 94.

33) If yes, could you tell more?

1.	The NARO is doing research on its control and it has been prioritised
2.	-

3.	-
4.	-
5.	There are bye-laws and quarantine requlations with regards to movement of planting materials, coffee wastes etc. There is a BCTB National Task Force created by government. A government sanctioned BCTB management strategy currently under implementation
6.	The Uganda Coffee Development Authority (UCDA) that is in charge of coffee production and marketing in the country funds research and development activities for managing this insect pest
7.	Planting she'd trees with sap i.e not a host plant, use all methods to control like cultural, biological, chemical and physical
8.	-
9.	N/A
10.	-

Table 95.

34) What IPM practices do you suggest to the farmers against the coffee pests (BCTB inclusive)?

1.	Cutting off infested twigs and burning. Avoid intercropping with crops affected by similar pests, spraying with pesticides

2.	Intercropping with non host plants, proper sanitation and hygiene of tools used, avoid using infected materials, pruning and burning infected materials, keeping the garden weed free.
3.	Proper shade management, pruning and desuckering to encourage biological control by natural enemies, use of NARO beetle traps, chopping and burning affected plant parts, soil fertility enhancement, Use of clean planting materials, proper spacing, use of imidacropid based pesticides in case of heavy infestation
4.	removing of infested materials and burning them maintaining plant nutrition pruning and desuckering the coffee chemicals as last resort
5.	Phytosanitary measures, chemical control, trapping and biological control
6.	Start a coffee garden with clean planting materials from UCDA-certified nurseries, regular monitoring of pests, use recommended spacing of coffee and shade trees, proper soil and water conservation, maintain soil and plant nutrition, remove weeds and in case of high infestation, apply recommended insecticide
7.	-
8.	- Field sanitation i.e. pruning, desuckering - Reducing shade trees. - Planting recommended shade trees preferably sapy trees i.e. Ficus trees at recommended spacing 50ft x 50ft. - Burning pruned infested twigs. - Use of pesticide i.e. Imidacloprid 80 mL

9.	- Avoid alternative hosts in a coffee farm; - Burying or burning infected twigs - Remove heavily infected coffee plants - Chemical control using environmentally friendly pesticides
10.	-

Table 96.

35) Are there any management practices singled out for BCTB specially? (Yes/ Maybe/ No)

1.	Yes
2.	Maybe
3.	Yes
4.	Yes
5.	Yes
6.	Yes
7.	No
8.	Yes

9.	No
10.	Yes

Table 97.

36) Could you mention some, if yes

1.	Cutting off infested twigs and burning them
2.	-
3.	Avoiding alternate host trees such as Albizia Chinensis in coffee fields
4.	cutting of infested materials and burning them, maintaining plant nutrition, pruning and desuckering the coffee, spraying using imdacroprid and Orius
5.	Phytosanitary, chemical, BCTB Trap and Biological control
6.	in addition to the above - trim off and burn BCTB-infested materials - with the characteristic entry holes, in case of chemical control - mix 4 mls of imidacloprid and 6 mls of tebuconazole in 1 liter of water
7.	-
8.	-

9.	N/A
10.	Mechanical control by continuously removing the infected/dry twigs and burning them to break the cycle of the pest.

Table 98.

36) What is the recommended spacing in coffee gardens? (Between coffee)

1.	3m
2.	10ft by 10 ft
3.	3mX3m in robusta coffee and 2.5mX2.5m in Arabica Coffee
4.	3m x 3m
5.	3 x 3 metres
6.	Robusta - 3 m and Arabica 2.5 m
7.	10' x 10'
8.	3m x 3m for Robusta Coffee
9.	3m x 3m (3m)

10.	(10 x 10) ft

Table 99.

37) What is the recommended spacing in coffee gardens? (Between coffee and intercrop)

1.	1.5 m when intercropped with bananas
2.	10ft by 10ft or 12ft by 12ft based on type of intercrop.
3.	-
4.	1.5m
5.	Question not clear
6.	Robusta 3 m and Arabica 2.5
7.	20' x 20'
8.	1.5m x 3m x 1.5m coffee and banana
9.	Depends on the main crop and age of coffee. Usually it is 1m.
10.	(10 x 20) ft

Table 100.

38) What is the recommended spacing in coffee gardens? (Between the intercrop)

1.	3m
2.	Depends on type of intercrop, for beans , you just plant at recommended spacing in the 10ft by 10ft spacing gardens of coffee.
3.	6mX6m for bananas
4.	6m x 6m
5.	Banana is spaced at 6 x 6 meters
6.	Bananas are spaced at 6 x 6 m
7.	-
8.	6m x 6m - Banana intercrop
9.	Depends on crop eg. Bananas 6m, Beans 200m
10.	(20 x 20) ft

Table 101.

39) What is the recommended spacing in coffee gardens? (Between coffee and shade trees)

1.	7m
2.	its 10ft by 10ft for coffee and increase spacing of shade trees based on type, for cashew nut, spacing is 40ft by 4oft
3.	20-40m depending on the shade tree species and type of canopy
4.	15m
5.	Shade trees are spaced at 15 x 15 metres for medium canopy such as Albizia spp, and 20 x 20 metres for large canopy trees such as Ficus sp.
6.	Shade trees are spaced at 15 x 15 m
7.	40' x 40'
8.	15m x 15m - shade trees
9.	1 shade tree is 50m
10.	(20 x 20) ft

Table 102.

40) Why do you think is spacing important? (you can mention more than one)

1.	1. Land use Efficiency

	2. Shade for the coffee
2.	control measure for pests and diseases, reduces competition for nutrients
3.	Proper spacing ensures adequate utilization of land space without encouraging competition for nutrients and water, hence enhancing productivity. It also makes it easier to perform farm activities such as weeding, fertilizer application, pruning. Proper spacing also helps to control pest and disease spread
4.	reduces competition between the coffee plants and also intercrop
5.	Optimum yield; minimize pests and diseases
6.	Avoids competition for nutrients, space and water, reduces spread of pests and diseases from plant to plant
7.	Manage she'd of 50% to enable coffee ripen and perform well, it also checks on the pests and diseases
8.	-
9.	-
10.	-

Table 103.

41) Are there any trees/ intercrops that could act as a host for BCTB? (Yes/Maybe, not sure/ No)

1.	Yes
2.	Yes
3.	Yes
4.	Yes
5.	Yes
6.	Yes
7.	Yes
8.	Yes
9.	Yes
10.	Maybe, not sure

Table 104.

42) If yes, specify the trees

1.	Cocoa - because it harbours similar pests

2.	cocoa
3.	Alibizia chinensis, Maeosopsis emini (Umbrella tree), Avocado
4.	Albizia chenisis, Musizi, Avocado,
5.	Albizia chinensis, Macamia lutea, Perses Americana, Magnifera indica etc
6.	Albizia coriaria, Maesopsis eminii and Markhamia lutea
7.	Musizi, makamia, guava
8.	Musize, Markhamia lutea, Cocoa, Albizia, Avocado
9.	Albizia
10.	-

Table 105.

43) Could you please describe why it acts as a host?

1.	-
2.	its also a wood tree type

3.	They have soft branches which can easily be penetrated and bored into by the adult insects and have no repellant properties
4.	soft, sap not sticky
5.	BCTB is able lay eggs and creates its broods in their branches
6.	They are alternative host species of BCTB
7.	It has no sap
8.	These trees have similar twig/branch structure in that they a soft tissue inside the twig where the pest lays eggs and then the ambrosia fungi colonises for the larvae to feed on.
9.	Albizia is an alternative food for BCTB.
10.	-

Table 106.

44) What are the recommended intercrops with coffee?

1.	Bananas
2.	Banana, beans, ground nuts, soy beans, ficus etc
3.	Bananas, fruit trees, legumes such as beans in young coffee

4.	Banana
5.	Bananas, legumes
6.	Bananas and legumes
7.	Mvle, graveria, ficus spp
8.	-
9.	-
10.	Bananas

Table 107.

45) What are the reasons for this selection?

1.	Bananas provide shade to coffee plants
2.	They protect the soil from erosion and conserves moisture. some legumes are nitrogen fixers, thus improves on soil fertility, bananas prove shade to coffee and acts as wind breakers
3.	Bananas and fruit trees help to provide shade for the coffee and also provide food and supplementary income, legumes help in improving soil fertility through nitrogen fixation

4.	they don't competite with coffee interms of feeding space
5.	Do not suppress coffee yields; legumes boost soil fertility
6.	Bananas provide shade to young coffee and do not compete with mature coffee, legumes provide nutrients through nitrogen fixation and can act as cover crops to conserve moisture as well as controlling weeds
7.	Have sap which cannot allow BCTB to hibernate and multiply
8.	Legumes fix atmospheric nitrogen into the soil. Ficus trees are not host for BCTB.
9.	-
10.	Mutual benefit by both crops (provision of shed by Banana trees as well as Mulch to coffee and vice versa.

Table 108.

46) What is the infestation level of the insect on shaded coffee vs non-shaded coffee? (More on shaded vs non-shaded vs almost the same)

1.	More on non-shaded coffee
2.	More on shaded coffee
3.	More on shaded coffee

4.	More on shaded coffee
5.	More on shaded coffee
6.	More on shaded coffee
7.	More on shaded coffee
8.	More on shaded coffee
9.	More on shaded coffee
10.	Almost equal on both

Table 109.

47) What is the reason behind this variation in the infestation levels?

1.	It is because the shades sometimes repel the fly and also provide alternative breeding ground
2.	highly shaded trees are protected from sunshine, that helps in killing the pest. shaded areas have poor aeration that increase rates of the spread.
3.	The BCTD thrives better in shaded conditions. Additionally shaded conditions do not favour biological control by predators as the BCTB may not easily be seen by the predators

4.	The micrclimate created causing multiply of the BCTB to increase
5.	Thrives more under moist shady conditions that protects them from dessication
6.	Shade provides conducive conditions for development of most insects
7.	Shed creates a favourable condition of BCTB to thrive better under that environment
8.	Coffee trees under shade are infested more because the micro-environment under the shade gives the pest favourable conditions to multiply. There is low aeration under shaded coffee trees which is not the case with non-shaded coffee.
9.	Increased humidity increases breeding rate of BCTB in shaded coffee.
10.	Subject for detailed study/research

Table 110.

48) Are there any crops/trees which can act as a repellent plant for the BCTB? (Yes/ Maybe, not sure/ No)

1.	No
2.	May be, not sure
3.	May be, not sure

4.	May be, not sure
5.	May be, not sure
6.	Yes
7.	May be, not sure
8.	May be, not sure
9.	May be, not sure
10.	May be, not sure

Table 111.

49) If yes, specify the trees

1.	-
2.	-
3.	-
4.	-

5.	NA
6.	Lemon grass (Cymbopogon spp.), Mexican Marigold (Targetes spp)
7.	-
8.	N/A
9.	N/A
10.	-

Table 112.

50) Could you please describe what mechanism makes it repellent?

1.	-
2.	-
3.	-
4.	-
5.	NA

6.	Behavioral
7.	-
8.	N/A
9.	N/A
10.	N/A

Table 113.

51) Have you noted any predatory activity on the BCTB? (other insects, birds, etc.)

1.	No
2.	
3.	Yes, by wasps
4.	yes
5.	Yes
6.	Yes

7.	Yes
8.	Not yet noted.
9.	Yes
10.	No

Table 114.

52) Has there been any research work done on the BCTB in Uganda? (Yes/ Maybe/ No)

1.	Yes
2.	Yes
3.	Yes
4.	Yes
5.	Yes
6.	Yes
7.	Maybe

8.	Yes
9.	Yes
10.	Yes

Table 115.

53) If yes, in what way is it beneficial to the farmers?

1.	-
2.	most of the research is implemented by the scientist, only extension agents who are able to access it get it to the farmers.
3.	Research on alternate host plants for the BCTB done by NaCORI has helped in enlighting farmers to avoid planting such trees in their coffee fields
4.	its advises them on how to manage it
5.	The findings have been packaged into a BCTB management recommendation (IPM package) that is currently being used by farmers.
6.	A cultural-based IPM package has been developed by NARO and being used by farmers
7.	

8.	Farmers are taught basing on that research recommendations how to manage BCTB with much emphasis being put on use Integrated Pest Management strategies.
9.	-
10.	NARO has generated research knowledge on the ecology and management of the coffee twig borer which extension workers are bringing on to the coffee farmers.

Table 116.

54) What is the rate of implementation of such works on farmer fields? (Out of 10)

1.	-
2.	4
3.	3
4.	7
5.	6
6.	6
7.	1
8.	6

9.	3
10.	3

Table 117.