ECONOMIC BURDEN OF *TUTA ABSOLUTA* AND POTENTIAL DEMAND OF AN INTEGRATED PEST MANAGEMENT STRATEGY AMONG TOMATO AGRIPRENEURS IN KENYA AND UGANDA

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this is my original work and has not been presented to any university for the award of a degree.

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This research proposal has been submitted with our approval as the university supervisors

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DEDICATION

This thesis is dedicated to my parents Michael Mutai, and Mercyline Toroitich, my siblings, Emmanuel Kiprotich,Beatrice Mutai, Kathryn Chepngeno, Valarie Terer, Kevin Bett, Linus Ngeno and the late Aimee Chebet who have consistently supported and encouraged my work.

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ABSTRACT

Tomatoes are important food and commercial crops to smallholder farmers in Kenya and Uganda. However, over the last five years, tomato productivity in both countries has been declining due to the attack of an invasive pest, tomato leaf miner (*Tuta absoluta)*. The main management method of the pest is the use of synthetic pesticides. Pesticides are not only harmful to human beings and the environment but also lead to increased cost of production thus reducing profits and pest resistance. Integrated Pest Management (IPM) technology is recommended as an alternative to the use of hazardous pesticides. The International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with development partners is seeking to introduce an IPM package for management of *Tuta absoluta* in Africa. There is however little information on the knowledge, attitude, and practices in the management of the tomato leaf miner among the tomato farmers. The economic burden of the pest is also not clearly documented as well as the willingness to adopt the IPM strategy in the sustainable management of the pest. The study seeks to fill this gap. Two counties in Kenya (Kirinyaga and Kajiado) and two Districts in Uganda (Mbale and Masaka) were purposively selected and 661 tomato farmers were randomly selected. Descriptive analysis the knowledge attitude and practices of tomato farmers in Kenya and Uganda. Descriptive statistics were used to estimate the economic burden of the pest. While binary logit was used to estimate the exante demand of IPM strategy. The study findings indicate that *T. absoluta* is the major pest affecting tomato production, causing 2461.203 Kgs/ acre in losses per year while in Uganda average of 168.90 kg/acre loss annually. Most farmers use synthetic pesticides to manage it. A significant proportion of the survey respondents were willing to adopt the IPM strategy. The probability of adopting the strategy was positively related to a farmer being male, shorter distance to inputs, training, good knowledge, good attitude, and good practices towards non pesticides. The adoption of the IPM strategy by the farmers will improve the welfare of tomatoes farmers and will subsequently lead to the increase of income in the long run.

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LIST OF ABBREVIATIONS AND ACRONYMS

3AD	African Agribusiness and Agro-industries Development Initiative
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information System
HCDA	Horticulture Crop Development Authority
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KNBS	Kenya National Bureau of Statistics
OECD	Organization for Economic Cooperation and Development
STATA	Statistics and Data
UBOS	Uganda National Bureau of Statistics

CHAPTER ONE

INTRODUCTION

1.1 Background information

Horticulture plays a key role in economic growth and income generation among smallholder rural poor in Sub-Saharan Africa (SSA). This is mainly achieved through export of horticultural products to developed nations, with East Africa contributing about 20% of the total horticultural export in SSA (OECD-FAO, 2016). The commonly exported horticultural products in SSA includes fresh vegetables, nuts, flowers, fruits, and also medicinal plants (De Blasis, 2020; Henson *et al.,* 2011; Moya *et al.,* 2019). In the horticultural sector, 20-35% of the total revenue is generated from export of fresh vegetables, mainly tomatoes potatoes, snow peas, among other vegetables (RSA, 2015).

Tomato (*Lycopersicon esculentum*) is the most popular vegetable, this is due to its multiple harvests and high profits (Mutayoba, 2018). In Kenya, it is among the high-value horticultural crops with respect to its volume turnover and profit margins (RSA, 2015). It is estimated that the total world production in 2017 was 182,301,395 tonnes. It is the sixth most valuable crop in Africa, contributing 21.5 million tonnes per year with Egypt as the leading producer, producing 7,297,108 tonnes. East Africa contributes to about 2 million tonnes annually with Kenya producing 283,000 tonnes while Uganda contributes over 40,124 tonnes (FAO, 2019).

Kenya’s production has been rising over the years with a 6% increase in 2016 in comparison to 2015 and a total return of over Ksh.13 billion. Kirinyaga County is the leading producer in the country, with over 15% of the total value of tomatoes, followed by Kajiado County (HCDA, 2016). Uganda is known for producing traditional staple foods like bananas, but the country has experienced a shift to the production of quick maturing vegetables like tomatoes (IPC, 2017). The major tomato growing districts include Mukono, Kayunga and Mubende districts among others (USAID, 2013).

The vegetable is yet to meet its production potential, compared to other countries such as Egypt and Nigeria. It is mostly affected by biotic and abiotic factors. Abiotic factors include the level of rainfall, climate, post-harvest losses, and soil fertility among others. The biotic factors are the biggest challenge to tomato production, they include both pests and diseases (HCDA, 2017). The major diseases affecting tomato production include early blight and late blight, wilt diseases, nutritional diseases nematodes and pests (Mwangi *et al.,* 2015). While the major insects affecting tomato production are Tomato Leaf Miner followed by other nematodes (Nderitu *et al.,* 2018).

Tomato Leaf miner (*Tuta Absoluta*) mainly invades solanaceous vegetables (black nightshade, potatoes, eggplant, pepper among other species), with the major host being tomatoes. The pest was first detected in South America (Spain) in 2006 and later spread into Europe, Asia and Northern African Countries (Desneux *et al.,* 2010). The first countries to be invaded in Africa were Tunisia and Morocco in 2008 from where it then spread to other regions (Rwomushana *et al.,* 2019). In Kenya, it was first detected in March 2014 in the coastal areas (IPC, 2017), while in Uganda it was detected later in 2015 in Mukono District (Tumuhaise *et al.,* 2016). The pest has continued to be a huge burden to tomato growers causing up to 80-100% loss in yield, both in protected and native fields if left uncontrolled (Rwomushana *et al.,* 2019).

T. absoluta affects both the quality and quantity of tomatoes. The pest causes increased cost of production and affects the established and new markets through trade quarantine (Never *et al.,* 2017). The pest attacks the tomato as larvae and as an adult. The larval stage is the most destructive stage of the pest, that perforated holes in stems, mines tomato leaves, and causes fruit rots. In severe invasions, it results in drying up of the whole field. Adult pests are hard to detect and control since they are mostly active at night. Seedlings are usually seriously affected by the pest (Zekeya *et al.,* 2017).

Generally, the use of synthetic pesticides is the most commonly used method for controlling pests in Africa. This is due to the ease of access (Mansour *et al.,* 2018). Studies in Central Uganda region show that there is extensive misuse of pesticides, with some farmers using as high as six times more than the recommended quantity by the manufacturers (Kaye *et al.,* 2015). The amounts and quality of pesticides used to control the pest are not usually regulated by most governments, leading to overuse. This causes significant health and environmental effects, especially to those who do not observe good agricultural practices while spraying, thus creating a spillover effect to consumers (Never *et al.,* 2017; Rwomushana *et al.,* 2019). According to the WHO classification, the pesticides used by smallholder farmers in Africa range from moderate to extremely hazardous, resulting to approximately 20,000 deaths yearly.

T. absoluta over time becomes resistant to a number of pesticides (Roditakis *et al.,* 2018). Acknowledging this resistance problem, the growers opt to use multiple pesticide brands seasonally, with the aim of increasing its effectiveness (Biondi *et al.,* 2018; Muriithi *et al.,* 2016). This use of multiple pesticides leads to increased costs of production. The pesticides are expensive to purchase and the use of several brands of pesticides at once becomes more costly, reducing their profits (Ii, 2022).

There is no clear pathway of dealing with the pest using a single product hence the need for the Integrated Pest Management (IPM) strategy, for sustainable management (Birhan, 2018).The use of IPM has been recommended by many researchers as an alternative to pesticides since it provides both sustainability and intensification thus improving agricultural productivity (Pretty & Bharucha, 2015). IPM is a sustainable way, human and environmentally friendly way of managing pests without the use of pesticides. However, most growers only use a few components of the package. Previous studies on IPM in controlling tomato pests, such as the fruit borer {*Helicoverpa armigera (L)}* have shown increased success rate through reduced costs and increased production compared to the use of pesticides (Gajanana *et al.*, 2006).

Therefore, the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with development partners seeks to introduce an IPM strategy includes the use of mass trapping, entomopathogenic fungal (EPF) based biopesticides, biorationals, host plant resistance, orchard sanitation, and biological control. These integrations of modified practices seek to sustainably manage *T. absoluta* by preventing it from infestation or containing them to the accepted economic threshold. Before the introduction of the IPM strategy, there is a need to know the knowledge, attitude, and practices of tomato growers in tomato production and pest management. Their knowledge regarding the pests' biology, spread and occurrence will determine the *ex-ante* demand of the IPM. Furthermore, the economic burden of the pest has not been clearly demonstrated in previous studies. This study seeks to address these missing gaps to effectively guide implementation of the IPM strategy.

1.2 Statement of the problem

Over the last 5 years, the tomato leaf miner (*Tuta absoluta*) has become a threat to smallholder tomato agripreneurs in Sub-Saharan Africa, including Kenya and Uganda. The pest affects both the quality and quantity of tomatoes produced, thus negatively impacting on farm output and revenue from the enterprise. There have been several efforts to control the pest, chiefly the use of pesticides. However, the continuous use of synthetic chemicals not only causes pests resistance and resurgences but also presents high human and environmental risks. Furthermore, pesticides are expensive and often unaffordable to most smallholder farm entrepreneurs. Researchers recommend the use of the Integrated Pest Management (IPM) strategy as a more sustainable alternative to the use of broad-spectrum pesticides. Past studies provide evidence that investments in IPM programs generate significant farm returns. The International Centre of Insect Physiology and Ecology (ICIPE) and partners have spearheaded the development and implementation of an IPM strategy for sustainable management of *Tuta absoluta*. However, there is limited knowledge in the economic burden of the pest, as well as farmer's current knowledge, attitude, and practices towards the pest. Furthermore, the potential demand for the proposed IPM strategy is not known. This study was conducted ex-ante introduction of the strategy to address these gaps that will guide successful implementation of the strategy among smallholder tomato entrepreneurs in Kenya and Uganda.

1.3 Objectives

1.3.1 General objective

To contribute towards increased tomato production of smallholder agriprenuers through sustainable management of the tomato leaf miner using an integrated pest management approach in Kenya and Uganda.

1.3.2 Specific 0bjectives

i. To assess the knowledge, attitude, and practices of tomato growers on tomato production and pest management in targeted areas in Kenya and Uganda.

ii. To determine the economic burden of *Tuta absoluta* in tomato production in Kenya and Uganda.

iii. To estimate the potential adoption of the IPM strategies for management of *Tuta absoluta* among tomato growers in Kenya and Uganda.

1.4 Research questions

i. What is the knowledge, attitude, and practices of tomato growers on tomato production and pest management?

ii. What is the economic burden of *Tuta absoluta* in tomato production?

iii. What is the potential adoption of the IPM strategies by the tomato growers in the management of *Tuta absoluta*?

1.5 Justification

Tomatoes are among the most important commercial vegetables in East Africa, therefore making the enterprise crucial in the region. However, the effects of *Tuta absoluta* on its revenue are far-reaching, causing up to 80% to 100% loss if left uncontrolled (Desneux *et al.*, 2010).The popularity of synthetic chemical use in managing it is not only costly but also has significant environmental and health effects. Farmers in developing countries continue to use pesticides due to the following reasons: easier accessibility, lack of regulations from the government, ignorance, illiteracy and their unwillingness to suffer economic loss (Atreya, 2007).

The smallholder agripreneurs are critical to the economic growth of a country, they offer employment opportunities, thus increased income leading to poverty reduction. The leaf miner has detrimental consequences on their earnings, thereby affecting their financial and economic situation. The IPM strategy is a sustainable alternative to pesticide use. It manages invasive pests in an environmentally and health-friendly way. Empirical evidence shows that the use of this innovation leads to increased yields and reduced production costs, therefore improving the standards of living of the growers. This is in line with the African Agribusiness and Agro-industries Development Initiative (3ADI) which aims at improving the productivity and profitability of agricultural produce through increased private sector participation (FAO/UNIDO, 2010) . Additionally, it is supported by the United Nations Sustainable Development Goals (SDG) which promotes poverty eradication, food security, well-being and sustainable economic development (OHCHR, 2017). Lastly, it also supported by Science, Technology and Innovation Strategy for Africa 2024 (STISA) strategy, pillar 3 which encourages innovation and entrepreneurship in attaining socio-economic development across Africa (AUC, 2014).

Therefore, there was a need for awareness of the ecology and occurrence of the pest and of alternative ways of managing the pest. The study provides empirical evidence on the economic impact of the pests as well as the ex-ante demand of IPM technology proposed by ICIPE and development partners before its diffusion. This study moreover aims to assists researchers, extension officers, and the government to make informed decisions on IPM strategy in tomato production and *T. absoluta* control.

1.6 Scope and limitation of the study

The study was carried out in selected areas in Kenya and Uganda, that is Kirinyaga county and Kajiado Counties in Kenya and Mbale and Masaka Districts in Uganda. The target was only focusing on small scale farmers. The factors of analysis were limited to some of the socio-economic factors and the level of awareness regarding the benefits of IPM strategy. The study will also be limited to information given since it also depends on farmer's truthfulness. Lastly, the data collected was only limited to cross-sectional data.

1.7 Definition of terms

Potential adoption: This is the exante demand of the IPM technology before its introduction to the growers.

Farm entrepreneurs/agripreneurs: Tomato farmers who grow tomatoes mainly for profitability through sales.

IPM strategy: It's an ecological sustainable means of managing an invasive pest. On the Tomato leaf Miner, it manages the pest with more emphasis on natural means such as the use of pheromone traps, hanging sticky traps, soil tillage and crop rotation.

Smallholders: Tomato farmers producing on an area of less than 2 acres.

Sustainable management: This is the efficient and effective control of the tomato leaf miner in a way that it doesn't have any spillover effects on human beings, animals, and the environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tomato agripreneurship

In Africa, increased crop productivity and easy access to domestic and export markets is the key to economic growth and enhanced food and nutritional security. Within the agricultural sector, horticulture crops generate more jobs per hectare than staple crops. Several Solanaceae vegetables are widely cultivated and consumed in Africa offering a reliable source of employment and income to small and medium-scale growers. Tomatoes are an important horticultural crop; this is attributed to their ability to generate high profits to smallholder agripreneurs. Tomato production is mainly done by the smallholder farmers in Africa, and it has significant results. In Uganda tomato farming is more common due to its contribution to increased income and employment opportunities to both small scale and large-scale farmers. For instance, in 2018, it is reported that tomatoes earned it is country $3,268,771 through exports to Kenya, DRC Congo, Rwanda and South Sudan (UNC, 2018).

Tomato enterprises, with appropriate marketing channels, contribute significantly to smallholder entrepreneurs in developing countries (Mutayoba, 2018). This enterprise is important in improving the lives of the smallholder farmers as well as reducing the poverty level. With involvement in different facets of the tomato supply chain, from small cooperatives to larger corporations, these businesses exhibit versatility. Through these channels, products navigate their way from the producer to the consumer, creating a streamlined process. Tomato marketing channels involve streamlined methods for promoting and distributing tomatoes. Key to success lies in incorporating branding, packaging, transportation, and target market strategies. The tomato venture contributes to improving the economic situation of smallholder entrepreneurs. The success of many developing countries hinges on supporting their smallholder entrepreneurs, which can lead to a reduction in poverty, improved food security, and rural development. For smallholder farmers, tomato enterprises can offer a dependable market, resulting in increased income and a higher standard of living. Larger markets can be linked to by enterprises, providing smallholder farmers with access to customers outside their local communities. Through tomato processing, businesses can unlock additional income opportunities while adding value to the crop. These businesses' growth can lead to job opportunities across various supply chain stages, benefiting both farmers and non-farm workers alike. This is attributed to the increased employment opportunities and the income it offers (Anang, 2013). Tomato enterprise profitability depends on efficient production techniques using modern inputs and technology. To ensure continuity of the enterprise, factors such as technology adoption, resource management, financial support, and research have to be addressed (Mutayoba, 2018).

Tomatoes demand is ever increasing. They are widely used as vegetables in the preparation of meals and at times consumed raw as fruits. The vegetable is highly nutritious, and it provides vitamins A and B. It is also recommended by nutritionists for patients who want to lose weight because of their low calories and carbs concentration (Saoji, 2016). In the Kenyan market, tomatoes are used as taste enhancers therefore, popular for fresh consumption and processing purposes (RSA, 2015). Tomato production as an entrepreneurial activity is however affected by several factors such as Lack of steady market, influx of tomatoes from neighboring countries, Middleman/broker challenge, increased cost of production because of increase in use of inputs especially pesticides, use of screen nets and green houses, abuse and misuse of pesticides and excess use of pesticides leading to exceed in maximum residual levels.

2.2 Overview of *Tuta absoluta*

Since its invasion in 2008, *T. absoluta* has affected over forty countries in Africa. This can be attributed to its adaptive capacity to various climatic conditions (Biondi *et al*., 2018; Mansour *et al*., 2018). The spread of the pest has been attributed to the importation of tomato fruit. The pest can be transported in its larvae form and can go unnoticed since it affects the fruit internally. The larvae and adults can also be found in packaging containers during importation. For instance, in Europe, this importation contributed to the entry and the spread of the pest, this led to the USDA-APHIS calling for quarantine and inspection of vegetables for the control imported *T. absoluta*. For the short distances, the pests spread through flight attacking different Solanaceous vegetables (Karadjova *et al.,* 2013).

Tuta absoluta, is an invasive pest which attacks more during warm seasons. The pest is mostly found in the African tropics due to its warm temperatures. Tomato is the major host crop for the pest. Tomatoes are mainly grown in the warm seasons, but during the cold seasons they are grown in green houses. *Tuta absoluta* has a life cycle of 24-38 days depending on the temperature. The female pest can lay up to 250 eggs and can reproduce 10-12 generations per year. It has four growths stages: the egg, larvae, pupa, adult. The egg is usually creamy white but turns yellow when it is about to hatch. Hatching takes 4-6 days after laying eggs. The next stage is the larval stage, it is the most destructive stage. The larvae feed on the leaves, stems and fruits causing significant damage to the plant. They are usually cream in colour with a dark head. This stage takes 8-9 days. The third stage is the pupation stage. It mainly takes place in the soil, on the leaf surface or within mines. They are brown in colour. In this stage there is not any damage to the plant. This takes 6-9 days. The last stage is the adulthood. *Tuta absoluta* can grow to a length of 5-6mm, with a life span of 10-15 days as an adult. At this stage it is difficult to control as it only feeds at night (Bhat *et al.,* 2019; Savvas *et al.,* 2013) .

2.3 Knowledge, attitude and practices (KAP) of tomato growers on pest management

By incorporating KAP, tomato growers gain a comprehensive understanding of pest management. To grow tomatoes successfully, one must recognize and comprehend pests' potential to harm plants, detect early signs of infestation, and employ effective pest management strategies. Pest management attitudes among tomato growers include their outlook and beliefs. The investigation scrutinizes their perspective on the significance of addressing pest issues, their willingness to adopt pest management techniques, and their attitude towards the obstacles posed by pests in tomato farming. Tomato growers' pest management actions and behaviors constitute their overall practices. Incorporating their knowledge and attitudes, they apply it. Pesticides and IPM strategies are employed to stop, observe, or regulate pests, forming part of their overall approach. Understanding tomato growers' levels of knowledge, motivation, and practical skills in addressing pest issues requires the collection of data on three dimensions during a KAP study (Andrade *et al.,* 2020; Nguyen *et al.,* 2019).

Investigating tomato cultivation through Knowledge Research might involve questioning farmers about pest management techniques, their life cycles, and pest-related concerns. Identifying knowledge gaps can be addressed through training or educational materials. Researchers can gauge tomato growers' views on the significance of effective pest control, as well as any potential obstacles or worries they may have regarding certain practices, such as pesticide application. Tomato growers' actual pest management procedures on their farms can be observed and inquired about by researchers. Providing a window into practical application, this shows whether knowledge and attitudes are in sync. Exposing the divide between growers' self-perceived knowledge and their actual actions, it provides a clearer picture of reality (Andrade *et al.,* 2020; Nguyen *et al.,* 2019).

The farmers’ knowledge, attitude and practices are important for the action plan against the species. Knowledge involves the general understanding of the pests correct identification, symptoms, its occurrence and taxonomy among others. In a study done by (Materu *et al.,* 2016) the lack of knowledge of the taxonomy and occurrence of the pest, led to significant economic losses even with the use of pesticides. Attitude is the pest perception by the growers, in relation to the pest damage and the effectiveness of the control practices. Previous studies on the pest in East Africa, reported that more than 80% of the tomato growers identify *Tuta absoluta* as the major pest affecting their tomatoes (Nderitu *et al.,* 2018).

The use of pesticides in developing countries is a common practice. This is due to the belief that the effects of the pesticides on maintaining the quality and quantity tomatoes produced is higher than the health effects. Pesticide use is a short-term control method for pests, they act faster compared to other control systems. Several studies have credited the age, gender, level of education and experience to the use of pesticides. Most of these farmers are not aware of the good agricultural practices, such as the correct dosages, required personal protective equipment and not following the stated hygienic guidelines while spraying. Therefore, they continue to apply more than the required sprays per season with the aim to increasing productivity, even though aware of the immediate effects of pesticide poisoning (Mohamed *et al.,* 2018).

Growers in Kenya and Uganda mainly rely on pesticides as the major way of controlling the pest. Most of these farmers have no knowledge of the proper way of applying pesticides and how to dispose of the empty containers. Their decision on which and how to use particular pesticide is based on information from their friends, neighbors, relatives, media and agrovets (Nguetti *et al.,* 2018; Oesterlund *et al.,* 2014).

In a study done by Atuhaire *et al.* (2017) in Uganda, showed that many farmers apply these pesticides a few days to the harvest and some even after harvest. This is because of the need to maintain the aesthetic appeal of the fruits to the consumers and to increase their shelf life. Due to their ignorance, they do not wash the tomatoes before sale, overlooking the pesticide residue remains on the vegetable, causing health effects to the consumers.

There are few studies focused on the growers KAP on management strategies of *Tuta absoluta* in Kenya and Uganda. As seen by a study done by (Nderitu *et al.,* 2018) on pest management practices in Kirinyanga County, Kenya. Using descriptive statistics, it is evident that farmers identified Tuta absoluta as the major pest affecting tomato production, 95% of the farmers used synthetic pesticides as a means of control, hence the need of the IPM strategy in the country.

Apart from this study looking only at the awareness of IPM technology as an alternative to synthetic pesticides in targeted parts of Kenya and Uganda and the existing practices will be considered focusing on their level of effectiveness, as done in previous studies. The study also focuses on their knowledge of pests, the ecology of the pest and infestation patterns. In general, it is believed that there is low knowledge, attitude, and practices on sustainable pest management. Therefore, there is a need to study the growers' knowledge, attitudes, and practices in pests' management to come up with a good and effective pest control strategy. This will in turn positively contribute to their living standards.

2.4 Pesticides as a pest management tool

With the increasing population pressure in developing countries, there is a need for sufficient food. Food production is by limited several factors including pests and diseases, among the major ones. Disrupted life cycles, behaviors, or physiology caused by pesticides hinder pest populations and damage. Pest management requires a strategic plan to prevent, reduce, or manage pest problems. An integrated approach that considers the environmental, economic, and societal aspects of pest interactions. Efficient pest control and ecosystem, human health protection are the ultimate goals of pest management. With pesticides, crops can thrive, shielded from pest attacks that might compromise their growth. The importance of this technique is heightened in regions where pests pose a substantial danger to food production. Pesticide concerns include their effects on pests, but also touch upon broader environmental and health issues. Pesticide chemicals help in creating this balance (Nderitu *et al.*, 2018).

Pratt *et al.* (2017) synthetic pesticides are the most popular way of controlling pests in Kenya. This is because of its easy accessibility and use. The use of these pesticides is mainly because of media and government influence. This is through continuous adverts and very little chemical control by the government (Mwangi *et al.,* 2015). In developing countries, vegetables normally attract different types of pests. *T. absoluta* is one of the major pests. The pesticide usage in controlling this pest is ever increasing since it is resistant to most pesticides resulting in a mixture of several. This consequently becomes expensive for the grower, increasing his cost of production. This also leads to serious health and environmental effects (Rwomushana *et al.*, 2019).

2.4.1 Environmental and health effects of pesticide use

The use of synthetic pesticides is usually linked with health and environmental effects. Pesticides can harm non-target organisms such pollinators like bees, beneficial insects, birds, and aquatic life. When considering the implications on the environment, this disruption may cause ecosystem imbalances and have an influence on biodiversity. Pesticides may unintentionally spread beyond the intended target area due to wind or incorrect application, harming nearby crops, waterways, and wildlife. Pesticides have the potential to contaminate groundwater or surface water sources through soil permeability. This may have an influence on drinking water quality and aquatic habitats. Some pesticides can build up in the food chain, with higher trophic level creatures building up higher quantities. Health concerns for predators and even humans consuming polluted species can result from this. Certain pesticides have the ability to linger in the environment for lengthy periods of time, harming crops across several seasons of cultivation and possibly having long-term effects on the environment. Pests may become resistant to insecticides over time, necessitating greater dosages or more potent poisons. As a result, pest populations may change and secondary pests that were previously managed by natural predators may appear (Roditakis *et al.*, 2018).

Considering the consequences on health, acute poisoning can occur as a direct result of pesticide exposure, whether it is by skin contact, inhalation, or ingestion. From skin irritation to serious respiratory or neurological disorders, this can result in a variety of health concerns. Chronic health hazards, such as developmental and reproductive abnormalities, endocrine disruption, and an increased risk of some malignancies, can be brought on by long-term exposure to low amounts of pesticides. Health effects like diarrhea, headaches, vomiting, stillbirths, miscarriages, asthma, cancer and even death can be caused by long term pesticide poisoning. The most affected are children since their immune system is not strong enough to handle this and pregnant women. Particularly at risk of exposure are agricultural workers, pesticide applicators, and others working in pesticide-intensive areas, who frequently face significant health hazards as a result of being in close proximity to pesticides. Even after a pesticide treatment, residues may still be present on crops. These residues, especially if pesticide limitations are exceeded, may have an adverse effect on consumer health when consumed. Due to their developing physiology and activities, such as frequent hand-to-mouth contact, children are frequently more susceptible to the effects of pesticides (UNICEF, 2018).

In a study done by Kaye *et al.* (2015) ow that the most used type of pesticides in Uganda is II pesticides. This type follows class 1 a and 1 b, which is the most harmful type of pesticides. These pesticides are poisonous and can cause significant effects to humans and the surrounding environment. According to UNICEF (2018), one can get affected through physical contact, digestion, and inhalation. The adversity of pesticide use is supported by a study done by Rwomushana *et al.* (2019) which showed that in most developing countries, there is about 99% of Pesticide Misuse by smallholder farmers.

A majority of these farmers are ignorant of the environmental and health effects when purchasing pesticides. This causes significant health and environmental effects, especially to those who do not observe good agricultural practices while spraying, thus creating a spillover effect to consumers (Never *et al.*, 2017; Rwomushana *et al.*, 2019). According to the WHO classification, the pesticides used by smallholder farmers in Africa range from moderate to extremely hazardous, resulting in approximately 20,000 deaths yearly.

It is estimated that 96.5% of tomato growers use pesticides. This is a high number but only 27% reported it to be effective. The ineffectiveness of the pesticides has prompted the use of several insecticides. In Kenya, most farmers applied more than one insecticide spray in a span of 3 months. This has led to increased adaptive resistance of the pest. Therefore, increasing the cost of production (Rwomushana *et al.*, 2019). In a study done by Muriithi *et al.* (2016) on Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in the more educated an individual is, the more the use of the pesticides, more education comes with more exposure and access to more information.

In Uganda, tomato farmers are among the highest users of pesticides despite the introduction of the IPM strategies in the country (Karungi *et al.*, 2011). Irrational distribution practice is the main utilization of pesticides in Uganda, activities such as repackaging and adulteration of pesticides is commonly done, for sale to unsuspecting illiterate and poor farmers (Karungi *et al.*, 2011). Most farmers in developing countries use pesticides without proper training or sufficient information by the extension officers. This is seen by a study done by (Naidoo *et al.*, 2010) on pesticide safety training and practices on women working in small-scale agriculture in South Africa shows that approximately 84% of the women had never attended any training on pesticide use.

Given the potential consequences, there is an increasing focus on implementing integrated pest management (IPM) strategies and researching pest control alternatives that rely less on chemical pesticides. This all-encompassing strategy seeks to successfully manage pests while minimizing the detrimental effects of pesticide use on the environment and human health.

2.5 Integrated pest management (IPM) as an alternative to pesticides

There is no single way of managing a pest, which is why IPM is the most recommended alternative of controlling pests by many scientists. This is because it involves an integration of relevant methods of pest control that ensure the pests are at an economically acceptable threshold. The IPM ensures that the use of pesticides is at a minimum level to ensure plant, human and animal health (Jones, 2014). It is the best alternative for synthetic pesticides.

There are different IPM packages for different crop pests. The IPM package is categorized into 3, Monitoring and Mass trapping, Cultural control, biological control. The proposed IPM package for *Tuta absoluta* includes mass trapping, entomopathogenic fungal (EPF) based biopesticides, biorationals, host plant resistance, orchard sanitation and biological control.

2.5.1 Monitoring and mass trapping

This is important for detecting and trapping insect pests. It involves the use of synthetic appeals through pheromone traps, delta traps and sticky water traps. Mass trapping aims at luring and trapping as many pests as possible. The virgin female moth releases a sex pheromone that attracts the male moths, the male moths are then trapped (Braham, 2014). Other lures such as food traps can also be used. When used integrated with other control systems it significantly contributes to the reduction of the extent and occurrence of *T. absoluta* compared to when used individually (Aksoy & Kovanci, 2016). This method works in trapping the males with an aim of reducing the total populations, however, this was ineffective as it was found that the females were able to reproduce without sex (Caparros *et al.,* 2012) this emphasizes the need of an integrated system. This method has been found to be effective in greenhouse and open field production of tomatoes (El-Aassar *et al.,* 2015). The effectiveness of this technique can be limited by such as inefficient trap design, high pest population, untimely pheromone release, attraction of only one sex; unsuitable positioning of traps and large migration of new pests from outside the area pheromone treated area (Savoldelli & Trematerra, 2011).

2.5.2 Biological control

They include Entomopathogenic fungal (EPF) based biopesticides and biorationals. Entomopathogenic fungal (EPF) based biopesticides are natural plant extract pesticides. They are fungus-based entomopathogens used in controlling insects. A number of the entomopathogenic species belong to the classes *Hyphomycetes, Zygomycetes*, and *Ascomycetes*. The most widely used entomopathogen is *Beauveria bassiana*, this is because of its ability against different insect species (Gillespie & Moorhouse, 1989). Studies show that *Metarhizium anisopliae* and *Beauveria bassiana* were able to control *Tuta absoluta* at every stage (Abd-El-Ghany *et al.,* 2018). The fungi grow naturally on soil, and they react with the insect pest on contact, thus, they are recommended for insects that feed on sap (Barbarin *et al.,* 2012). Currently, there are more than 170 commercially sold entomopathogenic products in Africa making them accessible (Faria & Wraight, 2007). EMF biopesticides are environmentally friendly and effective as seen in the control of wheat aphids, it caused a significant mortality rate when mixed with botanicals (Ali *et al.,* 2018). This type of control is usually adversely affected by climatic and environmental conditions.

Biorational are part of biological controls. This is an IPM strategy that involves the use of naturally occurring pesticide substances to control the pests. This strategy does not affect the environment, humans or plants and animals. The biorational substances work in two major ways, firstly, they enhance the plants resistance to pests and diseases. Secondly, they work directly against pests increasing the production of the said crops (Bereś, 2016; Matyjaszczyk, 2018). Biorationals unlike biopesticides are specific to a particular type of species and they do not affect the population of the targeted species entirely or directly (Rami Horowitz, 2009).

2.5.3 Cultural control

It includes host plant resistance and orchard sanitation**.** Host plant resistance is an IPM strategy to grow resistant crops. The pest species are mostly attracted to the host plants through visual, physical and chemical content. The pest then proceeds to attack the plant motivated by its nutrient contents and other factors (Duffey & Stout, 1996). In this element, the resistant genotype is integrated into the plant to reduce the attacks from the species. This method is however affected by the oral secretions of the pests leading to a decrease in plant immunity (Howe & Jander, 2008).

Naturally occurring crops in shrubs or forests create their own resistance that the planted crops lack, therefore the is a need to look for the elements lacking in these domesticated crops and integrate them so as to improve their resistance to pests (Stenberg, 2017). Recent studies on resistant studies of tomato varieties have shown that *Bacillus thuringiensis* cry1Ac (BT) tomato is highly resistant to the *T. absoluta* larvae, because it increases the mortality rate to 38% to 100% (Selale *et al.*, 2017). The host plant resistance cannot be singled out and used independently Just like other elements of the IPM, it is combined with other strategies to increase its effectiveness (Capinera, 2014).

Orchard sanitation is a cultural method used to prevent the occurrence of *T. absoluta*. It involves the gathering of attacked fruits, leaves and stems on the trees or fallen on the ground and dumping them properly (Ekesi *et al.*, 2010). This also involves paying special attention to the seeds for the existence of the pest before planting. Studies have shown fertilization of soils will elongate the growth of *T. absoluta* (Mohamadi *et al.*, 2017).

2.6 Benefits of IPM

Pesticides are designed to disrupt the life cycles, behaviors, or physiology of these pests, ultimately reducing their populations and minimizing the damage they cause. Pest management involves the deliberate planning and implementation of strategies to prevent, mitigate, or control pest-related problems. This encompasses a holistic approach that considers the ecological, economic, and social dimensions of pest interactions.

The use of IPM strategy as seen in the control of fruit flies by mango growers has led to a significant increase in income. The use of pesticides is less effective and therefore it needs several sprays per season, this is unlike the IPM technology which is cheaper and a safe means. The estimations distinguished between the effects of the various IPM components when used as a comparison to farmers' practices. Regardless of the IPM combination component employed, the study's descriptive statistics demonstrate that applying the IPM technique increased mango net revenue by an average of 48% when compared to the prior season. However, there were differences in the amount of net income improvement among treatments, with the posfb and posmatfb treatments showing the highest improvements and the pos therapy producing the least amount of net income growth. The use of IPM technology also indicated a decrease in the use of pesticides (Muriithi *et al.*, 2016).

The use of IPM according to Pretty & Bharucha (2015), leads to cost-saving, delay in pest resistance, environment and health friendly and finally better perspective on consumption of agricultural goods. Pest management aims to strike a balance between pest control effectiveness and minimizing negative impacts on non-target organisms, ecosystems, and human health. In agriculture, pesticides can safeguard crops from damage caused by pests, leading to increased yields and food security. This is especially crucial in regions where pests pose a significant threat to food production. A study done by Kibira *et al.* (2015) on fruit flies' infestation on mangoes shows that there was a significant economic difference between those who used IPM as a control strategy and those who used the traditional ways. Their level of mangoes rejection reduced. This improves their livelihood and their living conditions.

In a study done by Atuhaire *et al.* (2017) in Uganda showed that the use of IPM technology reduced the level of pesticide exposure to the farmers and the environment. The use of pesticides can also raise concerns, including the development of pesticide resistance among pests, environmental contamination, harm to non-target species, and potential risks to human health. IPM offers an approach that goes beyond relying solely on chemical pesticides to control pests. Instead, it encourages a more diversified and sustainable approach that reduces the negative environmental, health, and economic consequences associated with extensive pesticide use. IPM reduces the dependency on chemical pesticides by prioritizing other methods that can effectively control pests. IPM can lead to cost savings since it optimizes the use of various pest management methods and reduces the need for excessive pesticide application. By using a combination of approaches, IPM reduces the negative impact of pesticides on non-target organisms, water quality, and ecosystems. IPM aligns with principles of sustainability, promoting long-term ecological balance, soil health, and biodiversity. The diverse approaches in IPM can help delay the development of pest resistance to chemicals.

IPM supports beneficial organisms that can aid in pest control, contributing to healthier ecosystems. IPM strategies can be tailored to specific crops, regions, and ecosystems, maximizing effectiveness. By incorporating a variety of approaches, IPM effectively manages pests while minimizing the negative impacts on the environment, human health, and overall agricultural sustainability. It represents a more balanced and holistic way of achieving pest control objectives.

2.7 Challenges facing IPM strategy

Even though IPM is the most recommended strategy for dealing with a number of pests. It faces a lot of challenges in its use. The knowledge of IPM in developing countries is minimal, this can be attributed to the low level of education. Argues that the complicated nature of the

IPM elements contribute to its slow diffusion and use (Parsa *et al.,* 2014). Lack of enough training and the technical support to farmers is another challenge affecting IPM technology, most farmers are not aware of the technology and those who are aware do not know how to use it (Parsa *et al.,* 2014).

The government's action also plays a major role. For instance, revealed that in 2012 the Chinese government banned the use of certain compounds of pesticides after it caused a number of deaths, this led to increased use of the biological package of the IPM, which includes the rearing of the Trichogamma wasps. The IPM technology lacks proper channels of commercialization. This can be achieved through advertisement strategies. As compared to IPM, pesticides commercials are all over the internet and the mass media channels. The lack of proper diffusing, through the ICT media, can be associated with its elements being probably new to most farmers (Alwang *et al.,* 2019).

2.8 Economic burden of *Tuta absoluta*

Economic burden is a negative change in the producers' or consumers' welfare. In this case, the economic burden can be defined as the welfare loss to the growers as a result of *Tuta absoluta* in the production of tomatoes. The welfare is calculated as the difference in the market prices of tomatoes and the cost of production. Tomato leaf miner continues to cause increasing negative impacts globally. This can be attributed to increased trade and transport activities (Essl *et al.,* 2011). The effects can also be attributed to the ecology of the insect. The pest is a relatively new species in Africa and especially in East Africa, barely 5 years old but its effects cannot be understated.

Most developing countries depend on agriculture, more so small-scale farming. This makes them more vulnerable to the effects of the pests, however, there is little information on the economic impacts. In a study done by Nghiem *et al.* (2013) in Southeast Asia on the Economic and Environmental Impacts of Harmful Non-Indigenous Species, economic burden can be classified into human health and agricultural damage. Human health impacts are quantified as the costs incurred in the management of the species, the costs include the labour incurred and health effects of management. The agricultural effects were calculated in terms of yield, profit and income lost.

Damage control models by Lichtenberg and Zilberman has been used in several studies acknowledging the effects of pesticides in controlling pests. Pesticides were noted as an input, when used over time, leads to the general decrease in the output expected. This is as a result of its externalities such as health and environmental. In the study, this model was praised as the changes in damage control could be seen even with the overuse of pesticides (Sexton *et al.*, 2007).

In a study done by Muriithi *et al.* (2016) the study used the Difference in Difference model and household fixed effects regression models that account for unobserved heterogeneity across households, it revealed that the income of those who used the IPM technology improved compared to those who used their existing strategies, this contributed to decreased costs and not improved revenue.

In study on the economic impacts of vertebrate pests in Australia, the economic burden was calculated in terms of the agricultural loss in yield and the cost of management (Gong *et al.*, 2009). This loss of welfare was then referred to as net loss. The study used several ways to get the economic burden, first it compared the benefits and the costs of invasive pests using the economic standard of welfare. Secondly, the study used the economic loss framework where it calculated production losses and the direct and indirect expenditure incurred in the control of the pest. Lastly the study used the estimation of potential returns. This looks at a "without pest scenario and looks at what amount could be saved in that scenario. The total loss in the horticulture industry was found to be USD 734 million.

In a study done by Pratt *et al.* (2017) on the Economic impacts of invasive alien species on African smallholder livelihoods, collected data for the past five years and used it to estimate the future losses, in terms of the value of yields reducing the errors by using upper and lower limits. The losses in East Africa seem to be high, especially the production losses. Therefore, there is a need to calculate the cost incurred in the control of the pest.

Hoffmann & Broadhurst (2016) used the economic loss and expenditure method studying the economic impact of managing invasive species, the economic loss and expenditure method was used. It was estimated that nationally the government used USD 13.6 billion dollars in the year 2011-2012 as the total cost incurred. In the same way, the study will be conducted using a loss-expenditure framework. This will be a combination of the direct losses incurred in terms of yield added to the expenditure incurred in controlling the pest. This is a measurement in the loss of welfare as a result of the pest invasion.

2.8 Willingness to adopt an IPM technology

Potential adoption for a product or service can be explained through utility maximization. Farmers, in this case, are assumed to be rational, thus, they will, aim to maximize their utility subject to the budget constraint (Kimenju & De Groote, 2005). The tomato growers aim at reducing costs and increasing their returns. They will therefore be willing to pay for the new technology that leads to higher profits. Ex-ante demand for new technology is determined by the KAP of the technology by the growers.

The current IPM being proposed by ICIPE is a non-market good, therefore there is no definite way to calculate its, therefore the study of willingness to pay. According to Atreya (2007), the amount a grower is willing to pay for a fairly new technology (IPM) is influenced by the cost incurred in using the existing technology (pesticides). These costs are environmental and health costs. For example, the amount a grower is willing to pay not to get sick is his true willingness to pay.

Non-market goods can be valued through a stated preference or revealed preference. Revealed preference is used when the value of the good can be estimated by observing choices made by the individual consumer. Good is not hypothetical. Hedonic pricing and travel cost methods techniques are popular in calculating revealed preference method (Antony & Rao, 2010). This is not relevant in our study since we are dealing with a hypothetical good, hence the use of stated preference method.

2.8.1 Previous Studies on potential demand

In a study done by Barham (1996) on the adoption of BST by Wisconsin farmers, using the theory of utility maximization, it was argued that the ex-ante adoption depends on the general opinion of the technology. The majority of farmers as seen in the ex-post results were non-adopters because of the current regulations of the product and the uncertainty of the market. It is important to analyze the political atmosphere before the introduction of any technology for effective diffusion.

Most research on new technology shows that profitability affects the willingness to pay. A study done on the herbicide resistance maize technology, it showed that the noble farmers in Western Kenya were willing to adopt the new technology because it seemed profitable to them and provided private seed markets (De Groote *et al.*, 2008). This is supported by a report written by Caswell *et al.* (2003) on Agricultural Biotechnology: An Economic

Perspective, the expected demand of Biotechnologies was influenced by the expected profitability as a result of the technology being used as an input.

In some research, the ability to pay affects the growers' willingness to pay. This can be seen in a study done on the WTP on bananas in the Caribbean, the author used Choice modelling experiments and he argued that the farmers in the same ecological environment and same socioeconomic background, influenced each other in the uptake of new technologies (Blazy *et al.*, 2011).

2.9 Theoretical framework

The adoption of IPM strategy has its basis on the Random utility approach (Boxall & Adamowicz, 2002; Walker & Ben_Akiva, 2002). The grower is given the choice between two options, Y maintaining the status quo and X the IPM strategy respondent are asked to choose. The two choices have equal chances. He is assumed to choose the alternative with the highest utility, the utility of a choice depends on its attributes (Horowitz *et al*., 2014). Utility is a function of both priced and non-priced inputs. In our case, the non-priced inputs are the IPM technology. The farmer's willingness to pay for the IPM strategy will be denoted by X, while the alternative will be noted by Y. Indirect utility is a function of the deterministic and the stochastic variables. P represents available deterministic inputs while Q represents the laws and regulations that might affect the farmers' decision ε_i is the stochastic components that may influence the demand of either strategy. Therefore, a linear random model can be expressed as:

$$Ux = (X + P + Q) + \varepsilon_i \quad (1)$$

$$Uy = (Y + P + Q) + \varepsilon_i \quad (2)$$

If the farmer thinks $Ux > Uy$ then rationally, he will be willing to pay for IPM strategy and the reverse is true. The probability of the farmer choosing X over Y is:

$$WTP_x = P_x = \{(X_y + P_y + Q_y) - (X_x + P_x + Q_x) > \varepsilon_{ix} - \varepsilon_{iy}\} \quad (3)$$

The probability of choosing Y over X is

$$P_y = \{(X_x + P_x + Q_x) - (X_y + P_y + Q_y) > \varepsilon_{iy} - \varepsilon_{ix}\}$$

(4) Using linear equations

$$U_X = B_x X_i + \varepsilon_i \quad (5)$$

$$U_y = B_y X_i + \varepsilon_i \quad (6)$$

$$P_x = (U_x > U_y) \quad (7)$$

$$P_x = B_X X_i - B_y X_i + \varepsilon_x - \varepsilon_y > 0 \quad (8)$$

$$P_x = (B_X - B_{y)} + \varepsilon_x - \varepsilon_y > 0 \quad (9)$$

The probability of the grower WTP for the IPM technology is shown in the linear indirect equation.

The demand is affected by both deterministic (B_X andB_y) and the random factors ε_x (ε_x and ε_y).

2.10 Conceptual framework

The conceptual framework in Figure *1* shows the interrelationships in the study. The independent variables are the socioeconomic factors and the institutional and support services factors, with knowledge attitudes and practices as an intervening variable. Willingness to adopt is directly affected by socioeconomic factors, the institutional and support service factor and the knowledge, attitude and practices.

Socioeconomic factors such as age, gender, income, group involvement, education, household size, production quantity, production costs and income from tomatoes have a direct effect on the KAP of pest management practices. Age and education individually have a positive effect on the potential demand of the IPM strategy. Gender has an influence on the willingness to adopt as males will be more likely to adopt the IPM strategy easily compared to women. In contrast, the household size has a negative relation to the WTP (Moffat *et al.*, 2011). Increased income (on farm and off farm) and decreased productivity has a positive relationship with the ex-ante demand. The lower the TLU and people you can rely on, the less the willingness to adopt the IPM strategy.

Moderating factors such as the distance to the market, credit facilities, and extension services play a major role in the demand of IPM strategy. The availability of credit facilities will encourage farmers who do not use any form of pesticide management techniques. It is hypothesized that the closer the farmer to the market, the more informed he is. Thus, when knowledge is high, attitude is positive and the practices are harmful to humans and the environment, there is a higher potential demand for the strategy. Group involvement has a positive relation with the adoption of IPM (Atreya, 2007).

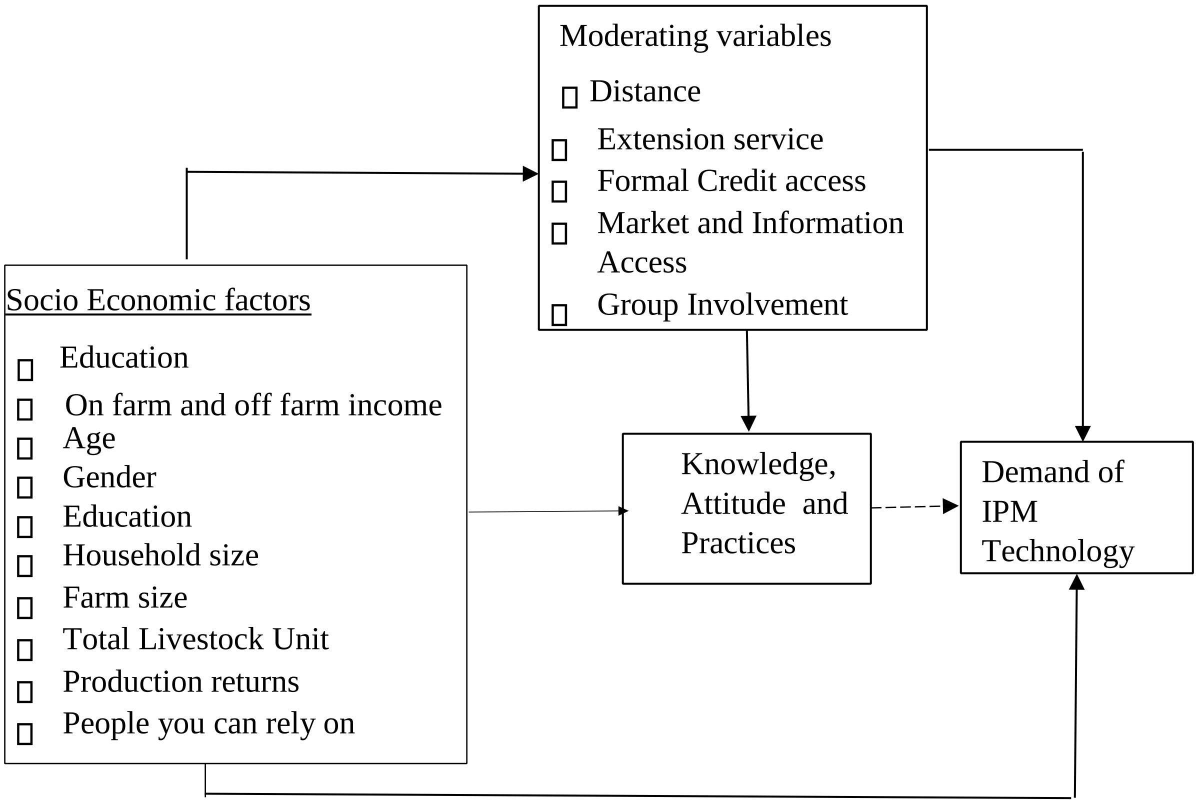


Figure 1: Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study was conducted in two countries Kenya (Figure *2*) and Uganda (Figure *3*). Two counties in Kenya (namely Kirinyaga and Kajiado) and two districts in Uganda (namely Mbale and Masaka) were purposively selected based on their predominant tomato production and are the project's target areas.

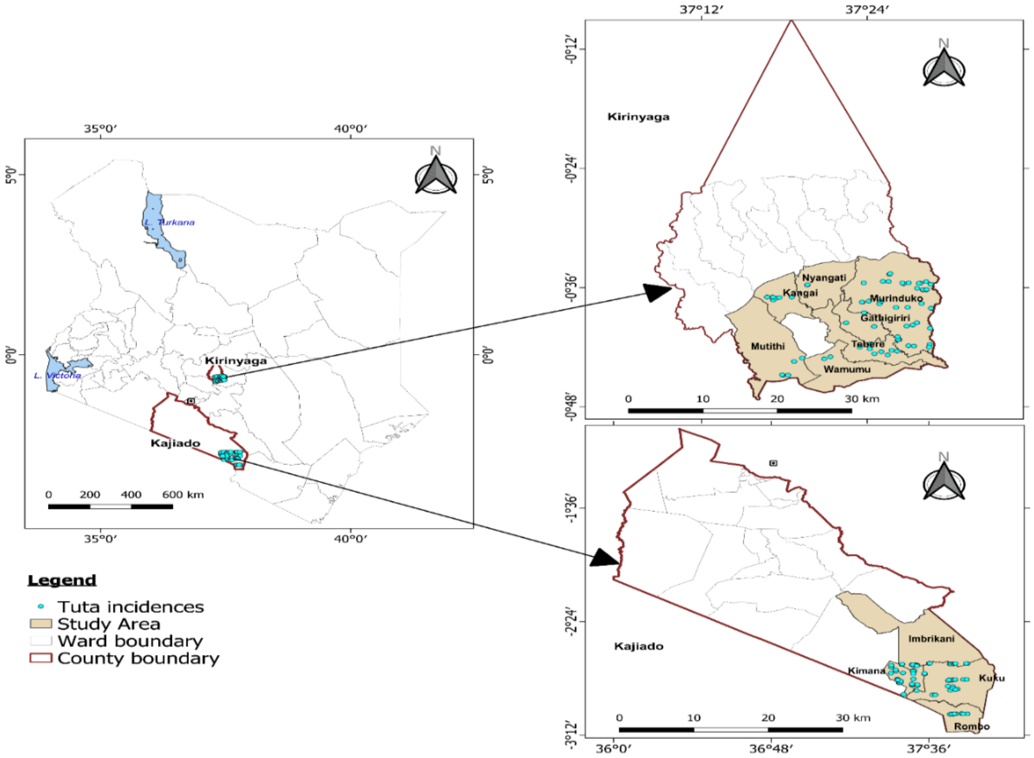


Figure 2: Map of Kenya showing Kirinyaga and Kajiado Counties

Source: *GIS unit ICIPE (11/06/2022)*

3.1.1 Kirinyaga county

Kirinyaga County is located in the central region of Kenya. It borders Nyeri to the west, Embu to the east and Murang'a County to the south. It lies on a latitude of 0.6591° S and longitude of 37.3827° E. The county is directly adjacent to Mt. Kenya with rich and fertile soils, the temperatures range from 120 C to 260 C annually. The county has two rainy seasons, the long ones that occur March to May and the shorter season that occurs between

October to December. Generally, it receives rainfall of 1250mm averagely. The county remains the highest producer of tomatoes owing to these climatic characteristics.

Kirinyaga County's major economic activity is Agriculture. It covers an area of 1482Km^2 with a population of 610,411(KNBS, 2019). It is divided into 5 Sub-counties namely, Kirinyaga East, Kirinyaga West, Mwea East, Mwea West and Kirinyaga Central.

3.1.2 Kajiado county

Kajiado County lies in the southern part of the rift valley region of Kenya. It lies on a latitude of 2.0981° S and longitude of 36.7820° E. Kajiado County is bordered by Tanzania to the south, Taita Taveta County to the east, Narok County to the west and Nakuru, Kiambu, Nairobi and Makueni Counties to the north. The county just as Kirinyaga County has two major rainy seasons; the long rains between March to May and the short seasons between October to December, with an average of 300-800mm. The temperatures lie between 10^0 C to 34^0 C. The warm climatic conditions make it the second producer of tomatoes in Kenya, following Kirinyaga County. The county's major economic activity is pastoralism since it lies in the ASAL region. It covers an area of 19600 Km^2 squared with a population of 1,117,840 (KNBS, 2019). There are five sub-counties found in this county, namely, Kajiado North, Kajiado East, Kajiado West, Kajiado South and Kajiado Central.

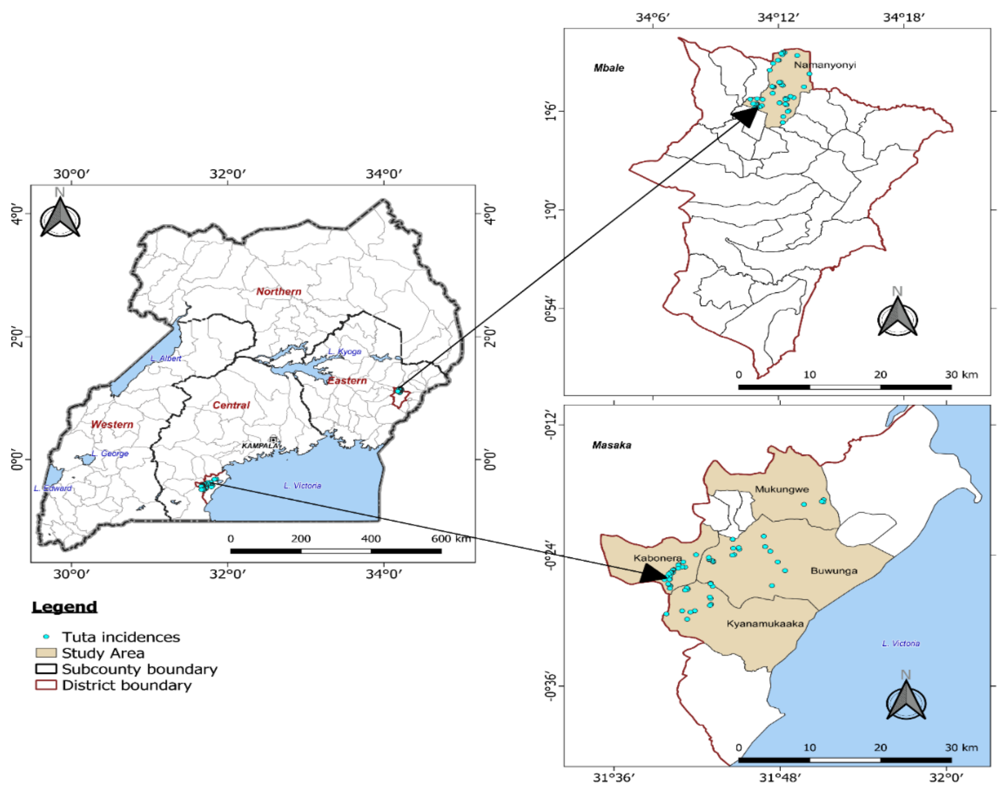


Figure 3: Map of Uganda showing Masaka and Mbale Districts

Source: *GIS unit ICIPE* (11/06/2022)

3.1.3 Masaka district

Masaka district is located 37km south of the equator in the Central region of Uganda. It lies on a latitude of 0.4464° S and longitude of 31.9018° E. The district is bordered by Bukomansimbi District to the north-west, Kalungu District to the north, Kalangala District to the Southeast, Rakai District to the south-west, and Lwengo District to the west. It covers an area of 1,295.6 km-squared with a population of 297,004 (UBOS, 2017). Generally, the climate in the district is warm. Temperature varies between 20^0 C to 25^O C. There is one rainy season that lasts for 9 months. The average amount of (precipitation) snow and rainfall is 999.9 mm annually.

3.1.4 Mbale district

Mbale is a district found in the Eastern part of Uganda. It borders Sironko district to the North, Tororo district to the south, Budaka district to the West, Bududa and Mafanwa districts to the East. The district lies on a latitude of 1.0344° N and longitude of 34.1977° E. It covers an area of approximately 518.8 Km^2 with a population of 96,189. The major economic activity in the region is agriculture. This is contributed to its favorable climate. The average temperature in the region is 23^0 C and the annual rainfall ranges about 1183 mm.

3.2 Sampling procedure and data source

The target population for this study was small-scale tomato growers in Kenya and Uganda. Data was collected using a face-to-face household survey. Multistage sampling was used in this study to select the sample of respondents. In the first stage, purposive sampling was used to select counties and districts, where tomato production is predominant in Kenya and Uganda respectively. These are Kirinyaga and Kajiado counties in Kenya, and Mbale and Masaka districts in Uganda. In the second stage, sub-counties were purposively selected based on the predominance in Tomato production. These had earlier been identified as the project benchmark sites. Two sub-counties in Kirinyaga County (namely Mwea East and Mwea West) and one in Kajiado County (namely Kajiado South sub-county). In Uganda, one sub-county from each district was selected, which is Bukhungu North and Bokoto from Mbale and Masaka Districts respectively. From each of the selected sub-counties, a list of tomato growers was developed with the help of front-line extension officers from the

Ministry of Agriculture. The list provided a sampling frame from which a sample of 662 respondents were interviewed based on the questionnaire attached at the appendix. The sample size was calculated using (Taherdoost, 2018) sample determination formula.

$$n = \frac{Z^2pq}{e^2} \tag{10}$$

Where:

n- is the sample size

Z - is the confidence level of 95% in a normal curve (1.96)

p - is the proportion of the population of interest (0.5)

q - is (1- p)

e - is the acceptable error (0.08), qualitative 0.03 and quantitative 0.05

$$\frac{1.96^2 \times 0.5 \times 0.5}{0.05^2} = 384 \tag{11}$$

The sample size for the study was 384 households for the two countries.

The data collection was carried out by trained enumerators supervised by the researcher using structured questionnaires designed in line with the objectives of the study. These provided ideas for developing and fine-tuning the survey. During the training the training, the enumerators were instructed on how to present the IPM strategy to the farmer, a handout with this information was provided to each trainee to guide them. Colored pictured to assist in visualization were used and respondents encouraged asking questions for clarification where necessary. This greatly assisted the farmers who were not familiar with the components of the package.

3.3 Methods of data collection

Cross-sectional data from small scale tomato growers was used in the study. Primary data was collected using the administration of questionnaires. A team of enumerators from the regions were trained to deal with the problem of language barrier.

3.4 Data analysis

The data was cleaned before analysis using STATA. The data was analyzed statistically using descriptive and inferential statistics. Descriptive analysis included measures of central tendencies, percentiles, measures of spread and dispersion, while inferential statistics included correlation and regression.

3.5 Analytical framework

Objective one: To assess the knowledge, attitudes, and practices of tomato growers on tomato production and pest management in Kenya and Uganda. To achieve this objective both descriptive analysis was used.

Objective two: To determine the economic burden of the tomato leaf miner in Kenya and Uganda descriptive statistics was used.

Gross margin analysis was then calculated to determine the viability of tomato farming. This is the difference between total revenue and the total variable cost (FAO, 1995), specified as:

$$GM = TR - TVC$$

(12)

Where:

GM = Gross Margin

TR = Total Revenue

TVC = Total Variable Cost

This can then be expanded as

$$\sum_{j=1}^{m} p_{ij} q_{ij} - \sum_{g=1}^{n} p_{ig} x_{ig}$$

(13)

Where:

p_{ij} = unit price of j^{th} output in relation to i^{th} the respondent

q_{ij} = quantity of the j^{th} output $(j = 1,2,3,..m)$

p_{ig} = unit price of i^{th} variable input in relation to i^{th} the respondent

x_{ig} = the quantity of the i^{th} variable output $(i = 1,2,3,..n)$

$\sum$ = summation sign

Total revenue was the total net profits in Kgs multiplied by the average price per Kgs. Total variable cost included the purchase of pesticides, seedlings, seeds, manure and fertilizers. Labor costs through weeding, harvesting, manure and chemical application, planting and trailing were also included in the variable costs. The gross margins were then compared between the two countries.

Objective three: To estimate the willingness to adopt for IPM technology. To analyze this objective, binary logit was used. The logit and probit models can be used interchangeably but in this case logit regression (Gujarati, 2004), logit model) was used to analyze the factors influencing the WTP for IPM. Multinomial or multivariate analysis was not used as it meant that the dependent variable is more than two while in this case the dependent variable is 1 or 0. This method is suitable for calculating categorical data compared to binary probit since it assumes that all factors are not correlated and have equal variance (Greene, 2003). Multinomial

The WTP was specified as 0 if the growers are not willing to pay and 1 if the growers are willing to pay for the IPM. The socioeconomic factors affecting WTP can be expressed in a logit regression as follows.

$$\text{WTP}=Ln \quad {}^{P}P \quad \frac{(Y=1)}{(Y=0)} = \beta_0 + \beta_1 X_1 + \beta_2 X_1 + ..\beta_n X_n + \varepsilon_i$$

(14)

The error terms are assumed to satisfy the property of independence from alternative variables. The probability that an individual will choose the IPM strategy is:

$$P_{iy} = \frac{e^{(D_{iy}-D_{ix})}}{1+e^{(D_{iy}-D_{ix})}}$$

(15)

The binary logit response takes two values. It is preferred since it does not assume normality, linearity or homoscedasticity of data (Kwak & Clayton-Matthews, 2002). This model can be represented as follows linearly:

$\text{Logit} = \ln \frac{P_i}{1-P_i} = \beta_O + \beta_1 X_1 + \beta_2 X_1 + \beta_3 X_3 + \cdots + \beta_n X_n + \mathcal{E}_i$

(16)

where p_i is the probability of being an adopter and $1 - P_i$ i the probability of being a non-adopter. β_0 is the constant, $\beta_1 to\, \beta_n$ are the correlation coefficients of the independent variables while the $X_{1\,to}\, X_n$ are the observable characteristics of the tomato growing household that are likely to affect adoption.

After estimation of the economic impact of the pest and willingness to pay of the strategy, the concept of the potential demand presents itself. This demand is not completely affected by the willingness to pay. Thus, making the demand uncertain. In such a scenario, sensitivity analysis is applied to assess the financial viability of adopting the IPM strategy. The strategy aims at minimizing the avoidable costs caused by the invasion. These expected returns can be analyzed through the Benefit-Cost Ratio (BCR) and the Net Present Value (NPV). While the BCR only reflects the efficiency of the project, ignoring the magnitude, the NPV identifies the best project and with the highest benefit, therefore, making the two ratios go hand in hand.

All the potential benefits and costs rising from the IPM strategy calculated. The two methods recognize the importance of lag periods in determining the potential returns. The lag period is the time taken for a farmer to adopt the strategy. The longer the lag period the lower the returns, as the returns will occur further into the future. According to the time value of money, the money you have at present is worth more than the money expected in future. Hence, discounting the future monetary benefits compared to present value of money, will show these differences in benefits over a period of time (Zerbe & Bellas, 2006). The two will be calculated as follows:

$BCR = \sum_{t-1}^{t} \frac{\frac{B_t}{(1+r)^t}}{\frac{C_t}{(1+r)^t}}$

(21)

$NPV = \frac{B_t}{(1+r)^t} - \frac{C_t}{(1+r)^t}$

(22)

Where;

t- Adoption lag time in years

Bt- Benefits in time t

Ct- Costs in time t

r- Discounting rate / percentage of avoidable costs

Returns with positive and higher NPV or BCR are considered feasible and lucrative. Higher returns will be as a result of short lag periods and higher avoidable cost.

3.6 Description of variables

Table 1: Description of variables

Variables	Definition	Measurement	Expected Sign
WTP	Growers' willingness to adopt the IPM strategy.	No (0) or yes (1)	+/-
Age	Age of growers	Number of years of household head	-
Sex	Gender of growers	Male (0) or female (1)	+/-
Educ	Level of education of the household head	Number of years in school	+
HH size	Household size	Number of individuals living in the same household	-
Market Distance	Distance to the market	Number of minutes	-
Extension	Visit by the government extension officers	Number of times in the last one year	+
Income	The proportion of income earned from the sale of tomatoes.	Percentage	+

Tomato Loss	The proportion of tomatoes lost due to *Tuta absoluta*.	Percentage	+
TLU	Livestock owned in Tropical Livestock Units	Number of livestock in the last one year	+/-
Group Involvement	Participation in group	No (0) or yes (1)	+/-
Credit	Access to credit	No (0) or yes (1)	+/-
Rely	Number of people you can rely on	Number of people	+/-
Confidence	Confidence in extension officers	No (0) or yes (1)	+/-
Farm size	Size of the farm in acre	Number of acres	+/-
Knowledge	Knowledge of T. absoluta and its management strategies	High or Low	+/-
Attitude	Attitude towards T. absoluta and its management practices	High or Low	+/-
Practices	Non pesticide practices in the control of *T. absoluta*	High or Low	

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is divided into two major sections. The first section discusses the descriptive results comprising farmers' socioeconomic characteristics. In the second section empirical results of Binary regression model including probit and logit regression.

4.2 Descriptive statistics

Descriptive statistics was used to analyses the respondent's knowledge attitude and practices on pests and the pests' management practices through the use of graphs, mode, percentages and charts. Bivariate analyses were carried out to determine the relationship between knowledge, attitudes, and practices of tomato growers on tomato production and pest management and the socioeconomic characteristics through the use of Persons Chi square test. The correlation values among KAP levels were calculated using Spearman's rank correlation.

4.3 Socioeconomic characteristics of sampled famers

The study was done in two countries, Kenya and Uganda with a total sample of 662 smallholder farmers. Kenya had 316 farmers from Kirinyaga and Kajiado counties while Uganda had 346 farmers from Mbale and Masaka Districts

4.3.1 Sex

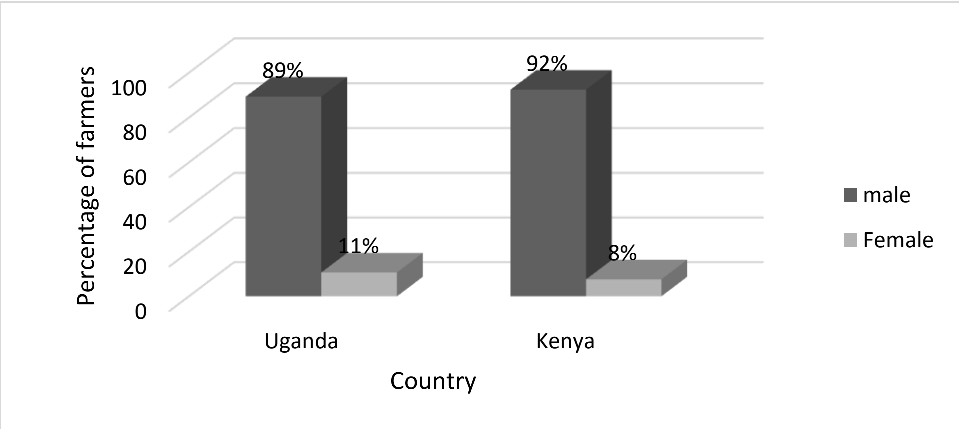


Figure 4: Sex of tomato farmer

The study revealed that in both countries the dominant producers of tomatoes were male. Kenya had 92% male and 8% female while Uganda had 89% male and 11% female. Refer to Figure 4. There is significant difference between the numbers of males and females practicing tomato production. This difference can be explained by a study done by (Amri &

Kimaro, 2010) which revealed that men are more involved in the production of cash crops compared to women who practice subsistence farming.

4.3.2 Age

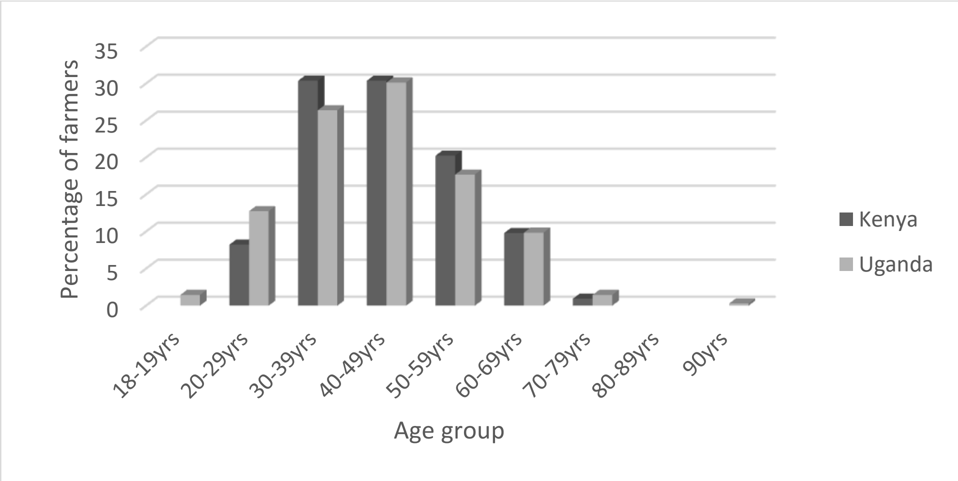


Figure 5: Age of tomato farmers

The majority of the household heads in Kenya were between 30-49 years while in Uganda it fell in between 40-49 years (Figure *5*). Uganda had the greatest variation in age as the youngest was in the 18–19-year bracket and oldest 90 years bracket compared to Kenya where the youngest had 20- 29 year bracket and the oldest was in the 70-79 year bracket. These results are in agreement with a study done by (Urama & Ozor, 2011) which showed that majority of small holder farmers are between the age bracket of 40-50 years. This is also supported by Yeboah *et al.* (2017) who revealed that the agricultural labor force in Sub-Saharan Africa is continuously growing younger.

4.3.2 Education

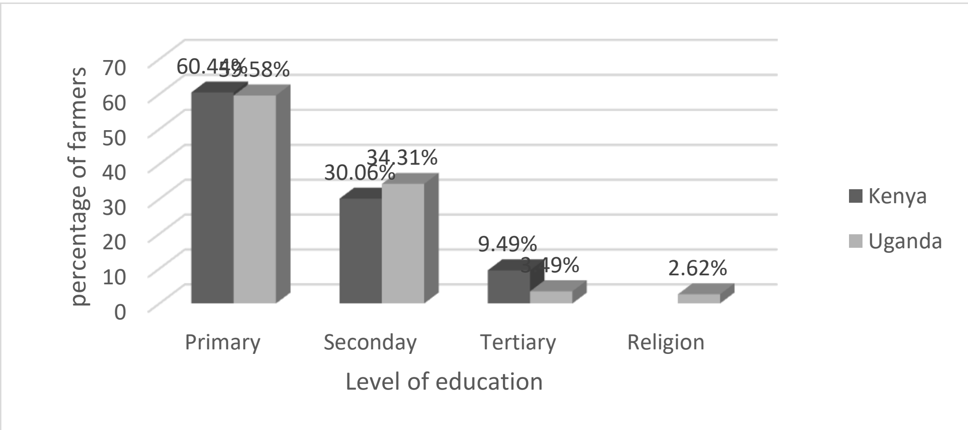
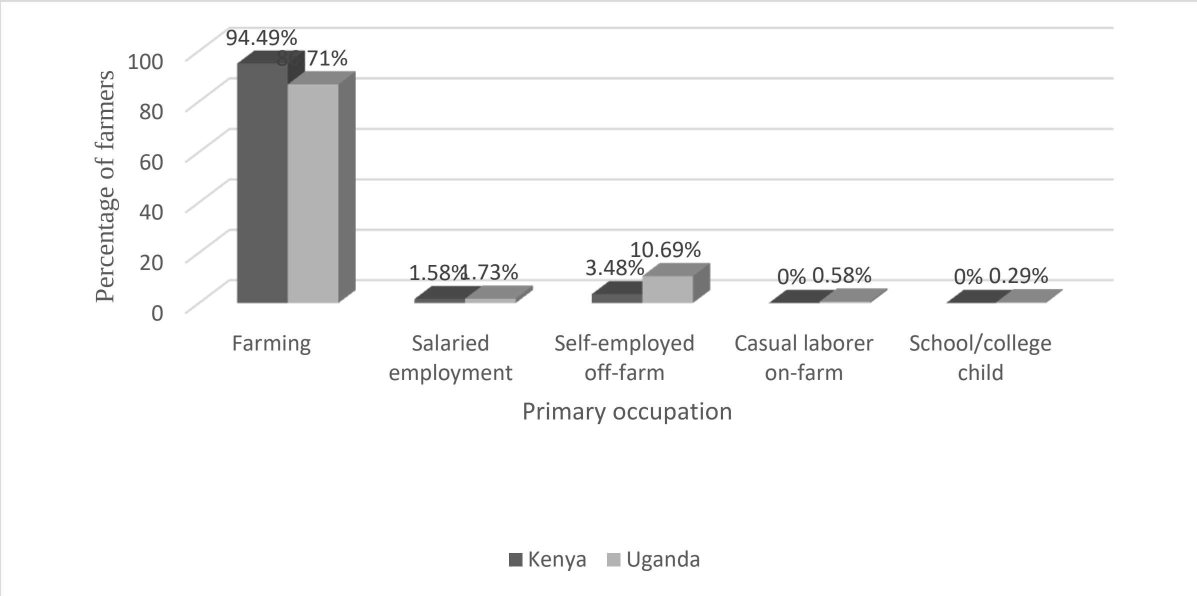


Figure 6: Education level of tomato farmers

The results indicate that in Kenya 60.44% and Uganda 59.58% had primary education. When looking at secondary education 30.06% in Kenya and Uganda 34.31%. 9.49% of respondents in Kenya and 3.49% in Uganda were found to have tertiary education.



4.3.4 Occupation

Figure 7: Primary occupation of tomato farmers

In both regions, majority of farmers were found to practice farming as their primary occupation, with Kenya having 95% and Uganda 87%. Other occupations such as self-employed off-farm had (3.48%) Kenya, Uganda (10.69%), while salaried employment had Kenya (1.58%) and Uganda (1.73%). Refer to Figure *7*.

4.3.5 Household size

Table 2: farmers´ household size

Country	Mean	Std.Dev.	Min	Max
Kenya	4.48	2.09	1	11
Uganda	6.13	2.80	1	16

The average size of the household members in the two countries ranged between 4-6 persons (Table *2*) with the average of Kenya being 4 and Uganda being 6. KNBS (2019) made a similar observation where the national average household size in Kenya is 4. While in

Uganda, the average household size slightly differed with the national average household size of 5 (UBS, 2014).

4.3.6 Distance to infrastructure

Table 3: Access to Infrastructure

	Proportion of farmers (minutes)	
Average distance in minutes	**Kenya**	**Uganda**
Distance to the village market from residence	26.53	24.92
Distance to the nearest source of inputs	44.38	84.29
Distance to the nearest trading Centre(Small-town) from residence	37.21	26.16
Distance to the nearest government extension office from residence	96.71	85.71
Distance to the nearest formal credit source from residence	117.09	63.17
Distance to the nearest government health Centre from residence	55.66	60.29
Distance to the nearest output market from residence	85.57	0

Table 3 presents summary statistics based on distance to various institutions. The distance to the village market from residence in both countries was shorter compared to the average distance of other amenities. The distance to the nearest government extension office and formal credit source was the furthest with over one hour of walking distance on average. The distance to the source of inputs in Kenya was shorter to the distance to the output market thus making the sale of tomatoes strained compared to purchasing inputs. This far distances, therefore, have an impact on the profitability of the tomatoes as they are produced close to market outlets. Furthermore, large distances lead to less access to information thus leading to low adoption IPM strategy (Buckmaster *et al.*, 2014).

4.3.7 Extension visit

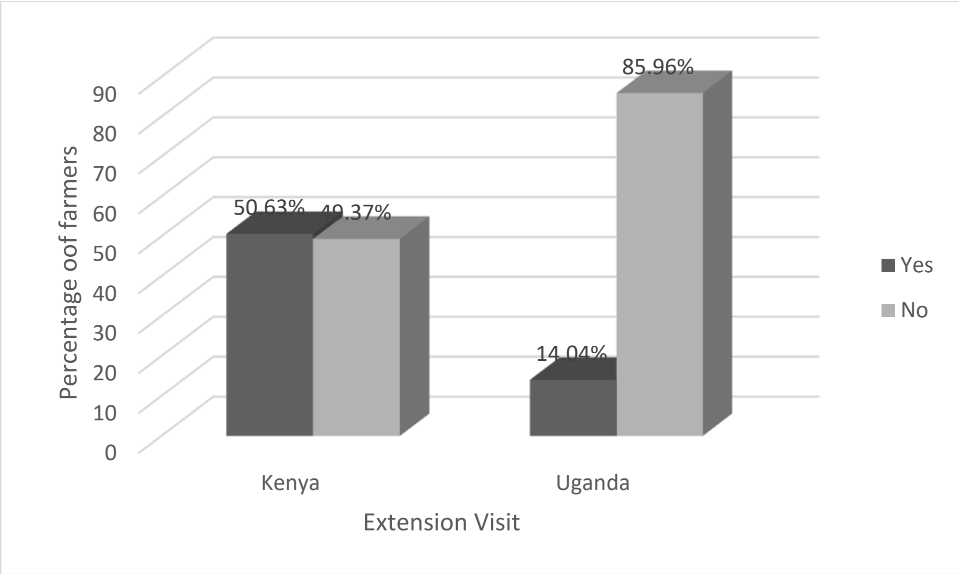


Figure 8: Extension visit to the farmers

The number of extension visits in Kenya is slightly higher compared to Uganda, with Kenya having 51% and Uganda 14%. This low turnout in extension visits can negatively influence the level of IPM strategy adoption in the two countries. According to Mohammadrezaei & Hayati (2013), extension services are important in influencing the level of technology uptake to farmers.

4.3.8 Land ownership

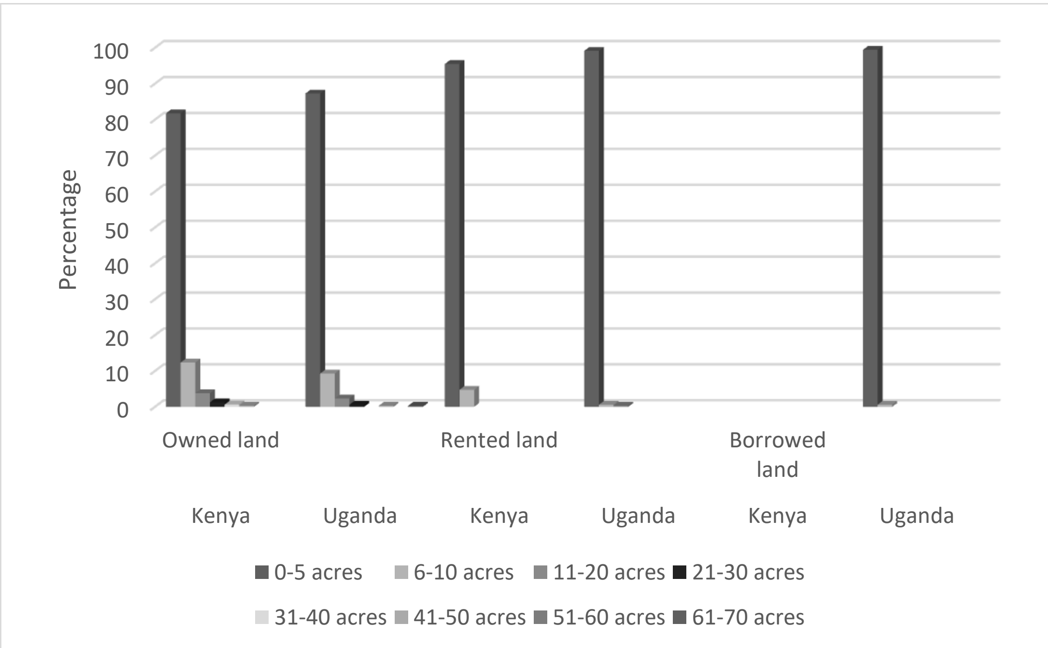


Figure 9: land ownership

In Kenya, 81.65% of the total population owned 5 acres and below of land while in Uganda 87.25% owned the same amount of land. About 95.25% and 99.13% in Kenya and Uganda respectively rented 5 acres and less of land. In Uganda, there was use of borrowed land and 100% of the population borrowed 10 acres and below of land.

Table 4: Land ownership and distribution

	Variable	**Mean (acres)**	**Std. Dev.**	**Min**	**Max**
Kenya	Owned land	4.03	3.55	0	45
	Rented Land	1.26	1.04	0	10
	Cultivated Land	3.56	2.79	0	24
	Tomatoes portion	1.62	1.39	0.05	9
Uganda	Owned land	3.38	2.48	0	70
	Rented Land	0.64	0.46	0	11
	Borrowed Land	0.30	0.28	0	9
	Cultivated land	3.25	3.15	0	60
	Tomatoes portion	0.70	0.46	0.13	3

In Kenya, an average of 4.03 acres and 1.26 acres as owned and rented land respectively was land accessible to the farmers, out of this, an average 3.56 acres was used for cultivation and only 1.62 acres was used for tomato production. In Uganda average 3.38 acres, 0.64 acres and 0.30 acres as owned, rented and borrowed land respectively was available for the farmers, an average of 3.25 acres was used for cultivation and from that, 0.70 acres was used for tomato production. In comparison, a larger percentage of land was distributed for tomatoes compared to Uganda.

4.3.9 Experience

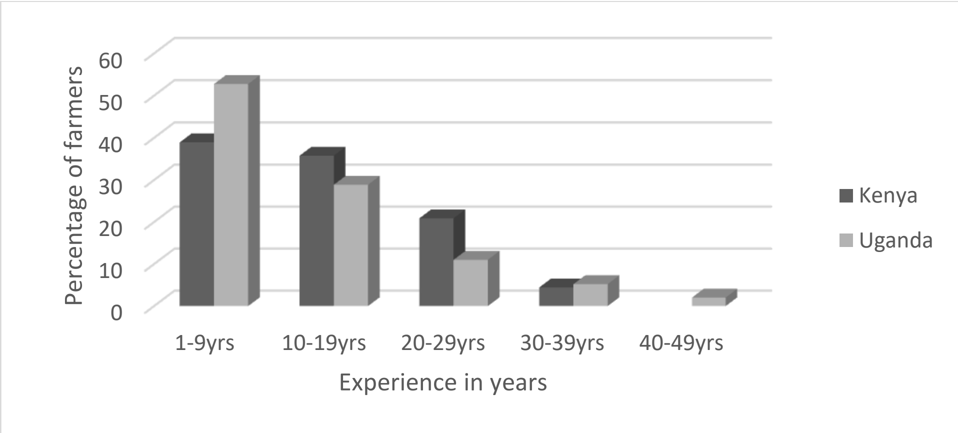


Figure 10: Farmers' experience in years

The average number of years in growing tomatoes in both countries was found to be between 10 to 15 years. Majority of farmers in both countries had farming experience of between 1-9 years. Uganda had the highest years of experience being in the category of 40-49 years while Kenya had was in 30 to 39 years.

4.4. Farmers´ knowledge, attitude and practices of tomato growers on tomato production and pest management

In order to determine the farmers´ knowledge on tomato and pests, they were asked to identify the major insect pests and diseases affecting their production and list the level of severity.

4.4.1 Tomato pests

T. absoluta was identified by farmers in Kenya (44.86%) and Uganda (32.36%) as the major pest affecting tomato production (Table 4). These results are supported by (Nderitu et al., 2018), where 90% of the farmers identified *T. absoluta* as a major pest. The other major pests identified were whiteflies (20.11%), red spider mite (15.11%) and thrips (14.66%) in Kenya. While in Uganda other major pests included; cutworm (19.73%), bollworm (15.87%) and aphids (13.57).

Table 5: Major insect pests affecting tomato production

	Proportion of farmers (percent)	
Pests	**Kenya**	**Uganda**
Leaf miner (*Tuta absoluta)*	44.86	32.36
White flies	20.11	9.60
Red spider mite	15.11	2.09
Thrips	14.66	6.16
Cut worm	5.23	19.73
Bollworm	5.11	15.87
Aphids	2.95	13.57
Other leaf miners	0.80	0.00
Leaf eaters	0.34	0.42
Locusts	0.00	0.21

4.4.2 Level of severity

About 77.50% of farmers regarded *T. absoluta* severity as high, hence it was considered the most severe, 5.25% and 7.65% considered the severity of the pest low and medium as shown in table 7 below. Other pests had such as whiteflies and red spider mite, generally had a severity of 54.85% and 54.40% respectively to tomato production. These results concur with the findings of Nderitu *et al.* (2018) where *T. absoluta* was the most severe pest followed by whiteflies where it affected tomatoes in Kirinyaga County. The least severe pests were Aphids (9%), other leaf miners (3.34%) and leaf eaters (0.83%).

Table 6: level of severity of the insect pest in Kenya

	Proportion of farmers (percent)			
Insect pest	**low**	**medium**	**High**	**Total**
leaf Miner (*Tuta absoluta*)	5.22	7.65	77.50	90.37
White flies	18.66	28.14	8.06	54.85
Red spider mite	28.36	21.04	5.00	54.40
Thrips	26.87	21.58	3.89	52.34
Cutworm	8.96	7.10	2.22	18.28
Bollworm	6.72	7.65	2.22	16.59
Aphids	2.99	5.74	0.28	9.00
Other leaf miners	2.24	0.55	0.56	3.34
leaf eaters	0.00	0.55	0.28	0.82

In Uganda, *T. absoluta* was regarded as the most severe (57.68%) in total followed by bollworm (14.49%) and cutworm (11.01%). *T. absoluta* was found to be highly severe by 56.7% of the farmers while 63.33% and 55.74% found the level of severity as medium and low respectively. Compared to Kenya, the effects of the pest was more severe in Kenya than in Uganda. The least severe insect pest was the red spider mite and the leaf-eaters, with a total level of severity of 0.87% and 0.58%, respectively.

Table 7: Level of severity of the insect pests in Uganda

	Proportion of farmers (percent)			
Insect pest	**Low**	**Medium**	**High**	**Total**
Leaf miner (*Tuta absoluta*)	55.74	63.33	56.7	57.68
Bollworm	11.48	21.67	13.39	14.49
Cutworm	6.56	3.33	14.29	11.01
Aphids	11.48	5	6.25	6.96
Thrips	4.92	0	5.36	4.35
White flies	6.56	5	3.13	4.06
Red spider mite	1.64	1.67	0.45	0.87
Leaf eaters	1.64	0	0.45	0.58

4.4.3 Tomato diseases

Table 8: Major diseases affecting tomato production

	Proportion of farmers (percent)	
Major diseases	**Uganda**	**Kenya**
Bacterial wilt	27.72	7.67
Late blight	19.31	34.40
Early blight	16.72	30.43
Fusarium wilt	11.65	12.66
Blossom	11.11	0.00
Bacterial cankers	3.56	2.05
Fungal diseases	2.80	0.00
Tomato mosaic virus	2.48	0.90
Spot	2.27	0.00
Root knot nematodes	1.62	7.16
Powdery mildew	0.54	4.73
Anthracnose	0.22	0.00

Unlike pests, the most common disease differed in the two countries In Uganda, the major disease affecting tomato production was Bacterial wilt (27.72%) followed by Late blight (19.31%) and Early blight (16.72%) while in Kenya the major diseases were Late Blight (34.40%), Early blight (30.43%) and Fusarium Wilt (12.66%). In both countries, early blight and late blight are common diseases affecting tomato production.

4.4.4 Level of severity

Table 9: Level of severity of the tomato diseases on tomato production Kenya

	Level of severity in percentage			
Diseases	**Low**	**Medium**	**High**	**Total**
Late Blight	28.29	33.85	39.33	33.82
Early blight	28.29	26.67	37.66	30.87
Fusarium wilt	13.82	15.38	7.53	12.24
bacterial wilt	10.53	7.18	6.69	8.13
Root knot nematodes	9.21	8.21	4.18	7.20
Powderly mildew	5.26	5.13	3.77	4.72
Bacteria cankers	3.95	2.56	0.00	2.17
Tomato mosaic virus	0.66	1.03	0.84	0.84

The total level of severity of major diseases affecting tomato production was Late Blight (33.82%), followed by early blight (30.87%) and fusarium wilt (12.24%) as shown in table 8. While the least had a percentage of 4.72%, 2.17% and 0.84% for Powderly mildew, Bacteria cankers and Tomato mosaic virus, respectively.

Table 10: Level of severity of the tomato diseases on tomato production Uganda

	Level of severity in percentage			
Diseases	**Low**	**Medium**	**High**	**Total**
Bacterial wilt	36.21	20	44.05	38.82
Late blight	17.24	27.27	25.11	24.12
Early blight	22.41	27.27	15.42	18.53
Fusarium wilt	13.79	9.09	5.29	7.35
Blossom	5.17	7.27	6.17	6.18
Spot	3.45	1.82	1.32	1.76
Bacterial cankers	1.72	1.82	1.32	1.47
Tomato mosaic virus	0	1.82	0.44	0.59
Anthracnose	0	1.82	0.44	0.59
Fungal diseases	0	1.82	0	0.29
Root knot nematodes	0	0	0.44	0.29

Compared to other diseases, bacterial wilt (38.82%) is the most severe, followed by late blight (24.12%) and early blight (18.53%), as shown in table 9 below. The least severe diseases include anthracnose (0.59%), fungal diseases (0.29%) and root knot nematodes.

4.4.5 Knowledge on *T. absoluta* and symptoms

Table 11: Knowledge percentage of *T. absoluta* Symptoms

Symptoms of *T.absoluta*	**Kenya**	**Uganda**
Create mines/galleries	23.41	44.83
Young larvae penetrate the leaves for feeding and development	21.35	7.80
female oviposit on all plant parts of tomatoes with a preference for leaves	12.64	12.59
The pest attacks all aerial parts of the plant	14.61	8.40
Larvae also attacks stem, young shoots, flowers, apical buds and fruits	16.20	5.70
Heavy infestation leads to leaf defoliation and death of the plant	6.84	10.94
Mining damage on the stem causes malformation of the plant	3.84	7.05

Farmers who correctly identified T. *absoluta* as an invasive pest were subsequently assessed on their ability to recognize pest damage symptoms. The majority of respondents identified building mines/galleries, with 23.41 percent in Kenya and 44.83 percent in Uganda. Young larvae enter the leaves for eating and development, according to 21.35 percent of Kenyan farmers and 7.80 percent of Ugandan farmers. The majority of farmers classified these two symptoms as the most common, as this type of damage occurs during the larval stage, causing extensive harm to the leaves and fruits (Shree *et al*., 2018). Female oviposit was found on all plant portions of tomatoes, with a preference for the upper and lower parts of the leaf, by approximately 12.64 percent of farmers in Kenya and 12.59 percent of farmers in Uganda (Shiberu & Getu, 2017). The two least common symptoms are leaf defoliation and plant death caused by heavy infestation, and mining damage on the stem causing plant deformity. This effect could be due to the usage of pesticides early in the larval stage, prior to the plant's enhanced damage.

4.4.6 Non-pesticide (IPM) knowledge for control of *T. absoluta*

Table 12: Percentage of farmers aware of Non-pesticides

	Kenya		**Uganda**	
Perception statements	**Number of farmers aware**	**Aware (Percent)**	**Number of farmers aware**	**Aware (Percent)**
Crop rotation with non-host crop	121	76	309	91
Planting resistant/tolerant varieties	52	33	291	86
Soil tillage	40	25	282	83
Pick and destroy infected plant or plant parts	28	18	302	89
Apply Bio pesticides (e.g., neem et al)	44	28	179	53
Selecting healthy seeds or sanitizing seed treatment	33	21	206	61
Grow tomato under insect net or net house	16	10	260	77
Orchard sanitation (collecting fallen infested fruits and disposing away from the farm)	19	12	200	59
Adjust planting/harvesting dates to reduce pest damage	16	10	139	41
Use Pheromones traps for scouting, monitoring and mass trapping	65	41	42	12
Hang sticky traps	47	29	49	14
Adjust irrigation timing/amount to reduce pest damage	8	5	101	30
Using a barrier crop	6	4	60	18
Using water traps	15	9	29	9
Biological control using parasitosis/natural enemies	8	5	22	6

More farmers in Uganda (91%) had knowledge on non-pesticide control practices of *T. absoluta* compared to (76%) in Kenya. In both countries, majority of the farmers were aware of the cultural control practices, these include; crop rotation with non-host crop, Kenya 76%, Uganda 91%, planting resistant/tolerant varieties 33% Kenya, 86% Uganda, Soil tillage Kenya 25% and Uganda 83%, pick and destroy the infected plants or plant parts Kenya 18%, Uganda 89%. This practice was the most commonly known, this can be attributed to its low level of technicality and its ability to reduce the infestation levels (Peshin & Dhawan, 2009) compared to the knowledge of biological control. Similar results were observed in a study done by (Piñero & Keay, 2018) where cultural practices were known by majority farmers while biological control was the least known. The use of parasitosis/natural enemies recorded the least awareness. The knowledge on Pheromones traps for scouting, monitoring and mass trapping and sticky traps was fairly known to both farmers in Kenya and Uganda.

4.4.7 Non-pesticide (IPM) practices for control *T. absoluta*

Table 13: percentage of farmers using non-pesticide

	Kenya		**Uganda**	
	Number of farmers using	**Practice Percent**	**Number of farmers using**	**Practice Percent**
Crop rotation with non-host crop	115	72	296	87
Soil tillage	40	25	254	75
Planting resistant/tolerant varieties	29	18	234	69
Pick and destroy infected plant or plant parts	22	14	271	80
Grow tomato under insect net or net house	16	10	194	57
Selecting healthy seeds or sanitizing seed treatment	23	14	157	46
Orchard sanitation (collecting fallen infested fruits and disposing away from the farm)	11	7	164	48
Adjust planting/harvesting dates to reduce pest damage	11	7	104	31
Adjust irrigation timing/amount to reduce pest damage	8	5	76	22

Apply Bio pesticides (e.g. neem et al)	4	3	53	16
Using a barrier crop	3	2	27	8
Use Pheromones traps for scouting, monitoring and mass trapping	16	10	7	2
Hang sticky traps	7	4	10	3
Using water traps	6	4	14	4
Others non-pesticide control methods (specify)	6	4	12	4
Biological control using parasitosis/natural enemies	1	1	5	1

From the farmers who were aware of non-pesticides, their use and practice of this strategy was measured. A larger portion of the sample in both counties were found to use crop rotation with non-host crop, while the least was found to use biological control using parasitosis/natural enemies. These results were in agreement with their level of knowledge. Cultural methods such as; soil tillage, planting resistant/tolerant varieties, picking and destroying infected plants or plant parts, grow tomato under insect net or net house, selecting healthy seeds or sanitizing seed treatment, orchard sanitation (collecting fallen infested fruits and disposing away from the farm), adjusting planting/harvesting dates to reduce pest damage and adjusting irrigation timing/amount to reduce pest damage, were found to be the most commonly used type of non-pesticides. This can be attributed to the low costs and low level of technicality required compared to monitoring and mass trapping (Use Pheromones traps for scouting, monitoring and mass trapping, hanging sticky traps and using water traps) and biological control (Apply Biopesticides and Biological control using parasitosis/natural enemies), hence its low diffusion and use (Allahyari, 2017).

4.4.8 Knowledge and perception statements on *T. Absoluta*

The head and the spouse were given a series of knowledge and perception statements to test their attitude of *T. absoluta*. A higher percentage of farmers in both Kenya and Uganda had a right attitude on the perception and knowledge statements. In both countries, the head and the spouse agreed that *T. absoluta* was a threat to tomato production and caused affected the market value of tomatoes. They also all agreed that *T. absoluta* laid its eggs on all parts of the leaves especially the leaves. A higher percentage of the respondents believed that pesticides had an immediate effect on all insects Kenya having 96% head, 93% spouse, Uganda 75%

head, 63% spouse, but a lower percentage agreed on mixing different pesticides to make them more effective and Chemical pesticide alone can effectively control *T. absoluta*, Kenya 69% head, 47% spouse, Uganda 53% head and 35% spouse and Kenya 48% head, 55% spouse, Uganda 43% head and 33% spouse respectively. A large percentage disagreed on reporting *T. absoluta* infestation to government agricultural extension officers and the effectiveness of the extension officers in offering adequate advice on the management of *T. absoluta.* Most farmers believed that Non-pesticide (IPM) are a better alternative to synthetic chemicals since they were concerned about the short term and long term health effects of synthetic pesticides, their effects on animals as well as on the environment.

4.5 Economic burden of the tomato leaf miner in Kenya and Uganda

4.5.1 Descriptive statistics

Comparing the losses from pests and diseases, tomato leaf miner was the main contributor in Kenya causing an average of 2461.203 Kgs/ acre in losses per year while in Uganda diseases contributed a higher percentage causing an average of 452kg/acre loss annually. The tomato losses caused by *T. absoluta* in Uganda was averagely 168kg/acre per year. Pesticide was their main control method for pests and diseases in both countries. In Kenya, an average of $358 per acre annually was used in the control of all pests and diseases with the cost of controlling *T. absoluta* contributing to $298 per acre per year. In Uganda, the cost on pesticides was significantly lower compared to Kenya, having $28 spent on all pests and diseases and $23 in the control of *T. absoluta*. In both countries *T. absoluta* contributed to a higher expenditure cost in controlling it.

Table 14: Losses and expenditure as a result of pests and diseases

	Kenya		Uganda	
Variable	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
Gross tomato production (Kgs/acre)	15434.510	14251.950	4707.956	4064.707
Loss due to all pests (Kgs/acre)	3858.362	3788.800	413.833	402.162
Loss due to *T. absoluta* (Kgs/acre)	2461.203	2451.184	168.900	164.580
Loss due to diseases (Kgs/acre)	893.686	881.797	452.907	450.590
Net tomato production (Kgs/acre)	7867.439	7694.066	3634.874	3197.224
Total Insecticide cost due to all pests and disease (USD)	358.434	355.887	28.022	27.227
Insecticide cost spent on *T. absoluta* (USD)	298.289	293.411	23.866	23.510

4.5.2: Gross margin analysis

Despite the effects of pests and diseases, tomato production in both countries was found to be profitable. The average gross income was $17917.63 in Kenya and $3182.84 in Uganda (Table 2). The variable costs included the input and labor costs, which were $3346.29 and $949.26 in Kenya and Uganda respectively. Subsequently, the tomato production gross margin was $17,918 and $3,183 for Kenya and Uganda respectively, suggesting positive returns to tomato enterprises despite the high cost of production and high pre- and post-harvest losses due to *T. absoluta* and other pests.

Table 15: Gross margin analysis of tomato farmers

	Kenya	Uganda
Output		
Produce (Kgs/per ha)	38123.24	11628.66
Price per Kg (USD)	0.56	0.35
Total output (USD)	21445.29	4093.63
Variable cost (USD)		
Seed purchased	248.66	58.13
Seedlings purchased	127.86	15.47
Fertilizer	393.18	143.14

Manure	224.04	138.16
Pesticide	1114.61	30.74
Labour cost (USD)		
Digging/ploughing	159.42	94.47
Planting	92.54	42.64
Manure application	69.69	39.66
Fertilizer application	64.08	34.10
Weeding	178.46	71.16
Trailing	295.06	48.60
Chemical application	185.49	103.16
Harvesting	374.57	91.36
Total variable cost	3346.29	949.26
Gross Margin	17917.63	3182.84

4.7 Potential adoption of the IPM strategy

Table 16 below shows the potential *T. absoluta* IPM adoption patterns among tomato farmers in Kenya and Uganda based on the willingness to pay responses according to the year they were willing to start using the IPM strategy. In the non-adopter classification, we had 5 % in Kenya and 33% in Uganda, while the adopter category had 95% and 66% in Kenya and Uganda respectively.

Table 16: Potential adoption patterns of Tomato leaf miner IPM by tomato farmers in Kenya and Uganda

	Kenya		**Uganda**	
	N	**%**	**N**	**%**
Non adopters	16	5	116	33
Adopters	300	95	229	66
Total	316	100	345	100

Explanatory variables as described in Table 17 below, were used to evaluate the factor affecting potential demand for *T. absoluta*. In Kenya, the main factors influencing the potential demand were distance to inputs, training, knowledge, and practice levels while in

Uganda the factors affecting potential demand include, gender, distance to the nearest government extension agricultural office, and attitude score. Gender had a positive relationship with the potential demand in Uganda, meaning the males were more likely to be early adopters compared to the females. This is because men are usually involved with the decision-making while women are mostly involved in domestic activities. Distance to inputs suppliers was found to have a positive relation with adoption. The individuals who were further from the source of inputs were less likely to be adopters compared to individuals in close proximity (Muriithi *et al.,* 2020). Long distances to input suppliers leads to increased costs through transaction costs to farmers. Training was also found to be positively related to IPM adoption. Farmers who attended the training were more likely to be early adopters compared to farmers who never attended the training.

In Uganda, distance to the nearest government agricultural extension office was found to be negatively related to the potential demand for the IPM strategy. These results were found to be different from our expected hypothesis contrary to the expected results where individuals located further from the agricultural extension offices were more likely to be adopters compared to those located close by (Martey *et al.,* 2013).

Contrary to our expectations, knowledge level was found to have a negative relation with potential demand for IPM. This can be attributed to, the more knowledge the farmers had on the pest symptoms, occurrence and non-pesticides use, the more they become cautious of the IPM strategy effectiveness before they adopt it. The practice level was positively correlated with the potential demand in Kenya, this showed, the individuals who had good practices (were currently using some elements of the IPM) were more likely to be early adopters compared to the farmers who had bad practices. The attitude score had a positive relation with the potential adoption in Uganda. The farmers having a good attitude were more likely to be adopters compared to the individuals who had a bad attitude. The attitudes scores were based on the symptoms, occurrence and effects of the *T. absoluta* to tomato production.

Table 177: Factors affecting ex-ante demand in Kenya and Uganda

	Kenya			Uganda		
	Coefficients	**Standard error**	**Marginal effects**	**Coefficients**	**Standard error**	**Marginal effects**
Dependent Variable						
Potential Demand						
Household characteristics						
Sex	0.000	0.021	0.000	0.001	0.008	0.000
Age	1.058	0.447	0.022	0.246*	0.209	0.079
Education	-0.100	0.062	-0.001	-0.034	0.025	-0.012
Household size (adult equivalent)	0.005	0.282	0.000	0.085	0.090	0.028
Experience	0.001	0.027	0.000	-0.002	0.009	0.000
Household resources						
Proportion of income from tomatoes	0.002	0.008	0.000	-0.002	0.004	-0.002
Total Farm size	0.105	0.079	0.001	0.007	0.023	0.000
Livestock owned in Tropical Livestock Units (TLU)	-0.003	0.012	0.000	-0.009	0.053	-0.002
Credit constraint	-0.098	0.374	-0.001	-0.030	0.169	0.000
Have access to off-farm income	0.677	0.53	0.004	-0.246	0.174	-0.090
Access to market and institutional information						
Distance to inputs	0.014**	0.014	0.000	-0.004	0.001	-0.002
Distance to the nearest agricultural extension office	-0.004	0.002	0.000	-0.001**	0.001	0.000

Attended training	0.329**	0.387	0.002	0.498	0.183	0.158
Knowledge attitude and practices						
Knowledge level	-0.316**	0.612	-0.003	0.626	0.193	0.190
Attitude level	1.158	0.421	0.014	0.144**	0.176	0.038
Practice level	1.059**	0.631	0.007	-0.509	0.187	-0.153
Social capital and networks						
Number of people that can be relied on in critical needs	-0.01	0.018	0.000	0.008	0.007	0.003
Confidence in extension officers	0.165	0.42	0.001	-0.225	0.190	-0.192
Location dummies						
Kirinyaga and Kajiado County	0.153	0.411				
Mbale and Masaka districts				0.243	0.208	0.343
Constant	-0.427	1.49		0.249	0.665	
Number of observations	316			343		
LR chi2(40)	44.52			71.310		
Pseudo R2	0.3516			0.163		
Log pseudo likelihood	-41.055981			-183.801		

Note: Source: Household survey; * p < 0.1; ** p < 0.05; *** p < 0.01

4.8 Sensitivity analysis

Using sensitivity analysis, the study estimated the potential returns in investing in the IPM strategy for the smallholder tomato farmers in the two countries. This was done by estimating the potential income that would be gained by using the alternative, which is the IPM strategy. The study estimated the initial cost of IPM technology to be $170 per hectare per season; this price was based on the cost of producing these IPM components from manufacturers, the market price of other IPM components for the control of other pests, and the cost of research. The computation was also done in collaboration with the biological team that developed the package and validated using field trials on the efficacy of the products.

The opportunity cost lost considered tomato losses as a result of *T. absoluta*. It shows the costs to be avoided with a primary focus on the probability that the farmer was likely to use IPM. As presented in Table 8, the NPV in Kenya ranged from $2851 to $8 while in Uganda it ranged from $990.64 to $646. This implies that $2851 would be saved in Kenya as a result of the immediate change from pesticide to using IPM. In Uganda, the highest amount that would have been saved was $992 if the switch from synthetic insecticides to IPM was done after 2 years.

For BCR, it was highest in Kenya when immediate change ($18) occurs and the lowest change was $1.09 after one year, while in Uganda the highest change would be realized after two years ($7) and the lowest ($5) after one year. For both NPV and BCR, the disparity in values between Uganda and Kenya can be linked to Kenya's higher severity of the pest invasion and use of pesticides than Uganda. The most intriguing part of the findings is that investing in the IPM strategy is economically desirable, whether adopting the IPM strategy immediately or adopting it after two years. A benefit-cost analysis of several scenarios on investment in IPM strategy for management of *T. absoluta* was carried out to evaluate the potential avoided loss of switching from the hazardous use of synthetic chemicals.

Table 18 Sensitivity analysis of the opportunity cost lost because of foregoing the use of pesticides for the management of *T. absoluta*

	Avoidable costs (USD)					
	5%	**10%**	**15%**	**20%**	**25%**	**30%**
Net Present Value (NPV)						
Kenya						
Immediately	2851.75	2851.75	2851.75	2851.75	2851.75	2851.75
After 1 year	1476.45	1409.33	1348.06	1291.89	1240.21	1192.51
After 2 years	13.56	12.35	11.30	10.38	9.56	8.84
Uganda						
Immediately	832.04	832.04	832.04	832.04	832.04	832.04
After 1 year	667.30	636.97	609.27	583.89	560.53	538.97
After 2 years	990.64	902.63	825.84	758.46	698.99	646.26
Benefit Cost Ratio (BCR)						
Kenya						
Immediately	17.77	17.77	17.77	17.77	17.77	17.77
After 1 year	10.12	10.12	10.12	10.12	10.12	10.12
After 2 years	1.09	1.09	1.09	1.09	1.09	1.09
Uganda						
Immediately	5.89	5.89	5.89	5.89	5.89	5.89
After 1 year	5.12	5.12	5.12	5.12	5.12	5.12
After 2 years	7.42	7.42	7.42	7.42	7.42	7.42

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Tomato production is a major source of income in Kenya and Uganda however its production is affected by a number of factors the major one being *T. absoluta.* This pest affects the quality and quantity of tomatoes hence limiting exports thus reducing the country’s` source of income. In an effort to control the pest, several strategies have been used, the major one being pesticides. Due to the adaptive resistance of the pest, farmers have ended up using multiple pesticides. The objectives of this study were: to assess the knowledge, attitude, and practices of tomato growers on tomato production and pest management in targeted areas in Kenya and Uganda, to determine the economic burden of *Tuta absoluta* in tomato production in Kenya and Uganda and lastly to estimate the willingness to adopt the IPM strategies for management of *Tuta absoluta* among tomato growers in Kenya and Uganda. Using primary data collected from smallholder farmers in Uganda and Kenya, this study aims to fill these research gaps.

In the first objective the study found that *T. absoluta* was the main pest affecting tomato farmers in both Kenya and Uganda. A number of farmers in both countries could identify at least one symptom of *T. absoluta* infestation. A majority of the farmers were not aware of some of the non-pesticide practices therefore did not practice it. On the knowledge and perception statements a number of respondents disagreed with the reporting of *T. absoluta* infestation to government agricultural extension officers as well as the effectiveness of the extension officers in providing appropriate management advice for *T. absoluta*. The majority of farmers agreed that non-pesticide (IPM) methods were preferable to synthetic chemicals because they were worried about the short- and long-term impacts of synthetic pesticides on human health, as well as the effects these chemicals had on both animals and the environment.

Looking at the second objective, the study findings showed that losses from pests were higher than the loss from diseases. When focusing on the pests, *T. absoluta* was seen as the major pest affecting tomato production, with most farmers using synthetic pesticides to manage it in both countries. The pest caused an average loss of 2461.203 Kgs/ acre in losses per year while in Uganda average of 168.90 kg/acre loss annually. In terms of gross margin tomato production in both countries was found to be profitable. The average gross income was $17917.63 in Kenya and $3182.84 in Uganda

In the last objective, the study showed that a significant proportion of the survey respondents were willing to adopt the IPM strategy (Kenya 95%, Uganda 66%). The probability of adopting the strategy was positively related to a farmer being male, shorter distance to inputs, training, good knowledge, good attitude, and good practices towards non pesticides. Calculating sensitivity analysis showed positive gains from the use of IPM, with a net present value (NPV) ranging from $8- $2851 in both countries. While in Kenya significant gains would be realized if the farmers switched to IPM immediately, in Uganda, significant gains would only be registered after two years of IPM implementation, with the difference attributed to the high cost of pesticides in Kenya in comparison with Uganda. In both scenarios, the NPV and BCR are positive; even with the most pessimistic avoidable cost of 5%, the opportunity cost is still evident (Gong *et al.,* 2009).

5.2 Recommendations

The study findings inform the following recommendations. Considering the economic burden, the use of pesticides is among the highest cost incurred associated with tomato production in Kenya and Uganda. Therefore, tomato farmers should consider the use of the IPM strategy since it is cheaper compared to the use conventional alternative such as synthetic pesticides.

Due to lack of awareness, many smallholder tomato farmers in Kenya and Uganda did not use the IPM strategies, which serve as a management tool and preventative measure against tomato leaf miners pests. To enhance the knowledge among smallholder tomato farmers, there is a need for extensive awareness campaigns. Emphasis should be placed on knowledge regarding pest management, especially in times of pest infestation or outbreak alerts. Smallholder tomato farmers should be trained in proper handling of chemical pesticides to avoid human poisoning. . Use of media to disseminate messages about *T. absoluta* may contribute to a further dissemination of knowledge on pest management strategies.

The study found that most of the farmers did not practice technical aspects of the IPM strategy, such a biological control among others. This was due to limited knowledge in aspects. Therefore, there is need for awareness programs to be set to improve the knowledge of these farmers. There should also training on the effects of Synthetic chemicals to the aquatic animals, birds, mammals and useful insects, surface and on human beings. This will help the farmer be health conscious on the pesticides and thus reducing its effects on human beings and environments in the long run.

On the potential to adopt, the government ought to take into account sponsoring adoption through donor groups with the usual pesticide rules. This would guarantee that the advantages of integrated pest management are fairly dispersed, particularly when it comes to the provision of extension services and management and technical training for new farmers. Co-operatives, marketers, and growers groups will work together with other industry players to develop guidelines for integrated pest management in production that will give growers transparency. Additionally, it will support efficient monitoring. They should also promote the foreseen cost effectiveness of the IPM strategy instead on using the broad range synthetic pesticides, as well as the health, environments and safety benefits.

The study looked at the potential adoption of the IPM strategy, it is essential to encourage farmers to come together because they can protect themselves from being taken advantage of by dealers. Additionally, it will increase their access to extension services, training in targeted integrated pest management, and perhaps even reduced-cost access to package components. Additionally, they would be in a better position to access better markets and agro-processing machinery for value addition because they will be able to understand the global market safety and quality standards. Using sensitivity analysis, Kenya and Uganda will benefit from adopting the strategy immediately as this will reduce the expenditure spent on synthetic pesticides and losses as a result of T. *absoluta* invasion, even with the most pessimistic scenario of 5%.

Furthermore, evidence for socio-economic impacts of introduced *Tuta absolut*a IPM technologies will be generated to facilitate informed policy decisions and uptake of effective T. absoluta IPM strategies. Capacity building and enhanced awareness of diverse stakeholders in tomato-value chain from the farmers to partners and policy makers on the proven technologies will be an integral component of the project for wider dissemination and sustainable pest management. The implementation will sustainably lead to the successfully and sustainably suppress *T. absoluta* infestation on solanaceous vegetables thereby increasing the quality and quantity of produce and enhancing food and nutritional security of the growers and countries at large.

5.3 Areas for further Research

We recommend a more research, particularly using panel data across various regions where the promotion and dissemination of IPM technology are being implemented. We recommend these studies to estimate the impact of the IPM strategy on tomato growers in both Kenya and Uganda.

Additionally, we recommended a further analysis to estimate the losses incurred due to Tuta *absoluta* beyond the farm gate, this research should include other value chain actors such as tomato traders. This will allow for a more comprehensive estimation of losses along the entire value chain in both Kenya and Uganda.

An ex-post study should be conducted sub-sequent to the introduction of the IPM strategy among farmers. This study should assess the strategy's impact on tomato farmers within the same target areas in Kenya and Uganda.

Furthermore, it is crucial to undertake a study concerning the health and environmental consequences of pesticide usage among smallholder tomato producers in response to Tuta *absoluta* in both Kenya and Uganda. This study should analyze the short-term and long-term effects of synthetic pesticides on the land, animals, and human health in these regions.

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APPENDICES

Appendix A: Selected Stata analysis result tables

Table A1: Correlation of Socioeconomic factors on Knowledge attitude and practices

Kenya	Knowledge score	Attitude Score	Practice Score
knowledge score	1		
Attitude Score	0.0721	1	
Practice Score	0.7066	0.0646	1
Uganda			
knowledge score	1		
Attitude Score	0.1908	1	
Practice Score	0.6371	0.1131	1

Table A2: Heteroscedasticity of the socio-economic factors on Knowledge attitude practice and potential demand

	Kenya		**Uganda**	
	chi2(1)	Prob > chi2	chi2(1)	Prob > chi2
Knowledge	4.58	0.0323	0.08	0.7727
Attitude	14.23	0.0002	6.56	0.0104
Practices	5.73	0.0167	4.38	0.0365
Potential Demand	126.81	0	15.03	0.001

Table A3: Multicollinearity of the socioeconomic factors affecting KAP and Potential Demand

	Kenya		Uganda	
	VIF	1/VIF	VIF	1/VIF
Sex	1.200	0.834	1.090	0.921
Age	1.600	0.625	1.380	0.726
Education	1.200	0.830	1.250	0.797
Household size (adult equivalent)	1.340	0.744	1.310	0.764
Experience	1.500	0.665	1.210	0.826
Proportion of income from tomatoes	1.220	0.819	1.120	0.891
Total Farm size	1.210	0.828	1.080	0.922
Livestock owned in Tropical Livestock Units (TLU)	1.190	0.839	1.150	0.871
Credit constraint	1.130	0.886	1.130	0.884
Have access to off-farm income	1.100	0.909	1.120	0.893
Distance to inputs	1.530	0.655	1.190	0.838
Distance to the nearest trading Centre	1.520	0.659	1.110	0.897
Distance to the nearest agricultural office	1.240	0.808	1.280	0.781
Attended training	1.160	0.861	1.120	0.889
Knowledge level	2.980	0.335	1.420	0.702
Attitude level	1.200	0.831	1.170	0.854
Practice level	2.830	0.353	1.290	0.777
Tomato group membership (1 = Yes, 0 = No)	1.130	0.886	1.120	0.896
Number of people that can be relied on in critical needs (number)	1.140	0.878	1.080	0.926

Confidence in extension officers	1.120	0.893	1.100	0.908
Kirinyaga and Kajiado County	1.390	0.722		
Mbale and Masaka districts			1.800	0.555
Mean VIF	1.430		1.220	

Appendix B: Questionnaire

Introductory statement:

Dear Sir/Madam, I work for the International Center of Insect Physiology and Ecology (icipe). We are conducting a survey to study the knowledge, perceptions and practices with regard to management of *Tuta absoluta* in tomato production and socio-economic contribution of Tomato to livelihoods in your village. This information is being collected **before ICIPE introduces an integrated** Pest Management (IPM) approach for suppression of this Your response to these questions would remain anonymous. Taking part in this study is voluntary. If you choose not to take part, you have the right not to participate and there will be no consequences. Thank you for your kind co-operation.

MODULE 1. Household and village identification

1.1 Household Identification **1**. County **2**.Sub-County/District **3**. Ward **4.** Location **5.** Sub-Location: **6.** Village: **7**. Name of household head (three names): **9.** Name of the respondent (three names): **12**. Cell phone number household head/ respondent		**1.2 Interview details** **14**. Date of interview (dd/mm/yyyy): **15.** Time started (24 HR) **16**. Name of enumerator **GPS reading of homestead.** **18.** Way point number **19.** Latitude (North) **20.** Longitude (East) **21.** Altitude (meter above sea level) **24. Have you grown tomato in the last 12 months [0=No 1=Yes]** *(if No, end the interview*)

MODULE 2: Household composition and characteristics and housing conditions

2.1 household composition and characteristics

ID CODE	Name of household member	Sex **1=Male** **0=Female**	Relationship to the household head **CODE 1**	Age	Marital status **CODE 2**	Education (years)	Primary occupation **CODE 3**	Months present in past year
	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
1								

CODE 1	**CODE 2**	**CODE 3**	
1.Household head	1.Married	1.Farming (crop+ livestock)	4.Casual laborer
2.Spouse	2.Divorced/separated	2.Salaried employment	6.School/college child
3.Son/daughter	4.Widow/widower	3.Self-employed	8.Other, specify…………..
4. Other	5.Never married		

1. Infrastructure (all distances in walking minutes)

B11. Distance to nearest source of inputs

B12. Distance to the nearest trading centre (small town) from residence

B13. Distance to the nearest government agricultural extension office from residence

B14. Distance to the nearest formal credit source from residence

B15. Distance to the nearest government health center from residence

B16. Distance to the nearest output market from residence

MODULE 3: Tomato production, perceived benefits and biotic constraints

3.1 For how long have you been growing tomato? [**C1a]** [_______] years

3.2 In what season(s) did you grow tomatoes last year? [**C1b**] [_____]

Wet season	2.Dry season	3.Throughout the year

3.3 What proportion of your TOTAL ANNUAL income comes **from tomato** [**C2]** [_____%]

3.4 What percentage of your total annual income is **from farm income** (all sources in the farm including crops and livestock? [**C3]** [_______ %]

3.5 Knowledge of tomato pests, diseases, control strategies and constraints in accessing key inputs and crop production

3.5.1 What are the **Three** major types of insect pests that caused damage to your tomato crops last year and what is their level of severity (*use table below) (Enumerators show the pictures)* **[C4]**

Tomato insect pests (CODE A)	If **YES,** level of severity **1=Low, 2=Medium, 3=High**
C4a	**C4b**

CODE A: Tomato pests	
1. Leaf miner *(tuta absoluta*)	7. Leaf eaters

2.	Thrips (Western flower thrips etc)	8.	Aphids
3.	Red spider mite	9.	Cut worm
4.	Other leaf miners (Lirimyza species)	10.	Others (specify)
5.	Ballworm		
6.	White flies		

3.5.2 (If Leaf miner is not mentioned in 3.5.1), Are you aware of leaf miner pest **[C5]** (*show photo)* [_____] 0=No 1=Yes

3.5.2.1 If YES (3.5.1), is this pest a major constraint in tomato production in your farm? **[C6]** [_____] 0=No 1=Yes

3.5.3 What proportion of the tomato production (*pre and post-harvest)* do you believe you lose due to **leaf miner (*Tuta absluta*)** **[C5]** [______%]

3.5.4 What proportion of the tomato production (*pre and post-harvest)* do you believe you lose due to **all other types** of pests **[C6]** [______%]?

3.5.5 Tell us the symptoms that you identify as **Leaf miner (*Tuta absoluta)*** infestation starting with the most common ones in your tomato production [*Enumerator show photos to identify different symptoms*) **[C7]** ***CODE A***

CODE A: Symptoms	
1.	The pest attacks all aerial parts of the plant
2.	Females oviposit on all plant parts of tomato with a preference for leaves (73%)
3.	Young larvae penetrate the leaves for feeding and development
4.	Create mines/galleries
5.	Larvae also attack the stems, young shoots, flowers, apical buds and fruits
6.	Heavy infestation leads to leaf defoliation and death of the plant
7.	Mining damage on stems causes malformation of the plant
8.	Other (specify)

3.5.6 How many times did you, or someone in your family, or hired laborer apply insecticides to your tomato plot to control *Tuta absoluta* in ALL 2018 cropping [**C8a]**? **Total number of applications** [_____]

3.5.7 How much did you spend on insecticides for *Tuta absoluta* control during ALL 2018 croppings [**C8b]** KES[______]

3.5.8 How much did you spend on all insecticides during the ALL 2018 tomato croppings? [**C8c]** KES [_______]

3.5.9 What are the **three** major diseases affect your tomato crop and the level of severity **[C9]**

Tomato diseases	If **YES,** level of severity **1=Low, 2=Medium, 3=High**
C9a	**C9b**
1.	

3.6 IPM knowledge, sources of information, perceptions and adoption and dis-adoption

3.6.1 Have you heard about **Non-synthetic pesticide** practices for control tomato insect pests?[**C10]** [________] 0=No 1=Yes

3.6.2 Have you been visited by an agricultural extension agents or others in the last **3 years**, who discussed **non-synthetic pesticides** means of controlling pests? [**C11**] [_____] 0=No 1=Yes

3.6.4 Have you heard about **Non-pesticide practices** for control of **Leaf miner (*Tuta absoluta)*** in tomato production [**C12]** [________] **0=No; 1=Yes**

If **YES (**3.6.3), tell us which non-pesticides practices you know and used to control **Leaf miner (*Tuta absoluta)*** [**C13**

Names of IPM/ Non-pesticide component/practice for suppressing *Tuta Absoluta*	Do you know [component] **1=yes; 0=no**	Are you currently (last season) using this component? **1=Yes 0=No**
C14a	**C14b**	**C14c**
1. Planting resistant/tolerant varieties		
2. Selecting healthy seeds or sanitizing seed treatment		
3. Soil tillage		
4. Crop rotation with non-host crop		
5. Adjust planting/harvesting dates to reduce pest damage		
6. Adjust irrigation timing/amount to reduce pest damage		

7.	Grow tomato under insect net or net house		
8.	Pick and destroy infected plant or plant parts		
9.	Orchard sanitation (collecting fallen infested fruits and disposing away from the farm)		
10.	Use Pheromones traps for scouting, monitoring and mass trapping		
11.	Hang sticky traps		
12.	Apply Bio pesticides (e.g. neem et al)		
13.	Biological control using parasitosis/natural enemies		
14.	Using a barrier crop		
15.	Using water traps		
16.	Others non-pesticide control methods (specify)		

3.6.5 Do you think the above non-pesticide practices are effective for management of *Tuta absoluta*? [**C15] [____]** 0=No, 1=Yes 3= do not know

3.6.6 Have you or any other member of the household received any training on tomato production in the last two years; **[C16**] [_____] 0=No, 1=Yes

3.6.7 If **yes (Qn. 3.6.6),** complete the table below

Type of training received	Who offered the training?	Who in the household was trained?
C17a	**C17b**	**C17c**

3.6.8 Knowledge and perception prevention and management of tomato infesting leaf miner (*tuta absoluta)*

		Head	Spouse
	knowledge and perceptions statements	2=Agree 1=Disagree 0=Don't know	2=Agree 1=Disagree 0=Don't know
	C18a	**C19b**	**C20c**
1.	*Tuta absoluta* species are a threat to horticulture (vegetable & fruits) industry		
2.	*Tuta absoluta* reduces the tomato quality		
3.	*Tuta absoluta* results to high loss of market value		
4.	*Tuta absoluta* are a trade quarantine problem		

5.	*Tuta absoluta* eggs are laid on all plant parts of tomato with a preference for leaves		
6.	Adult *Tuta absoluta* do not feed on fruits		
7.	Spread of *Tuta absoluta* can be prevented		
8.	You report *Tuta absoluta* infestation to gov. agricultural extension officers		
9.	Extension officers offers adequate advice on management of *Tuta absoluta*		
10.	Chemical pesticide alone can effectively control *Tuta absoluta*		
11.	Mixing different pesticides can make them more effective		
12.	I prefer using pesticides that kill all insects immediately		
13.	I am concerned of the short-term human health effects (mine and others) of using pesticides such as headache, eye irritation, nose bleeding etc		
14.	I am concerned of the long-term human health effects (mine and others) of using pesticides such as cancer		
15.	Synthetic chemicals present a major risk to the surface and ground water.		
16.	Synthetic chemicals present a major risk to the aquatic animals such as fish etc, birds, mammals and useful insects like bees.		
17.	Non-pesticide (IPM) are better alternative to synthetic chemicals		

MODULE 4: Land used by the households over the last 12 months.

4.1 Please provide the following information about the land used by the household in the last 12 months.

Total owned land in acres (including fallow and grazing area)	Rented-in (acres)	Size cultivated in 2018	Size allocated to tomatoes
D1	**D2**	**D3**	**D4**

4.2 How many times (cropping) did you plant tomato in your farm in 2018 and which months? [**D5]** [________times/cropping]

Cropping	Size allocated to tomatoes (acres)	**Variety**	Months in 2018 (from planting to end of harvesting)
D6a			**D6b**
1			

4.3 Plot information: please give details of plots cultivated and harvested for the last 12 months or 2018. agricultural practices, and cropping area <u>for tomato grown</u> by the household during the 2018 cropping season

Serial No	Plot ID	Plot areas (acres)	Season 1.Rainy 2.Dry 3=All	Sub-plot ID	Sub- plot area (acres)	Crops grown	If inter cropping with other crops, what is area under tomato	Sub-plot distance to residence (walking minutes)	Land quality	Who in the household manage this plot?	Total income generated from the crops (KES)
	D7	**D8**		**D9**	**D10**	**D11**	**D12**	**D13**	**D14**	**D15**	
1											

4.4 Seeds and seedlings used in tomato production in the last 12 months or 2018

4.4.1 What is the total cost of seeds purchased in the last 12 months? [**D16a]** KES [_____] (*write 0 if none)*

4.4.2 What is the total cost of seedlings purchased in the last 12 months? **[D16b]** KES [_____] (*write 0 if none)*

4.5 Fertilizer and manure use in tomato production in the last 12 months or 2018

4.5.1 Did you use fertilizer during the last 12 months in tomato production (e.g., DAP, NPK, CAN, UREA, TSP, Foliar, Mavuno etc) **[D17]** [____] 0=No 1=Yes

4.5.2 If YES, how much did you spend on fertilizer during the last 12 months **[D18] KES [______]**

4.5.3 Did you use manure during the last 12 months on tomato production **[D19]** [____] 0=No 1=Yes

4.5.4 If Yes, (4.5.3), was it own or bought? **[D20]** [_____] 0=Own 1=Bought 2=Given/gift

4.5.5 If bought manure, how much did you spend for the last 12 months [**D21) KES [_______] (***write 0 if none)*

4.6 Chemical application for <u>tomato</u> production in the last cropping or 2018

4.6.2 Please give the details of the type and quantity of chemicals used in ALL the cropping seasons in 2018

Did you use insecticides? 0=No 1=Yes	**If YES, which insecticides**	**Target Pest**	**Total cost (KES)**	**Did you use Fungicides? 0=No 1=Yes**	**If YES, which Fungicides**	**Target Disease**	**Total cost (KES)**	**Did you use Herbicides? 0=No 1=Yes**	**If YES, which Herbicides?**	**Total cost (KshS)**
D23a	**D23b**	**D23c**	**D23d**	**D24a**	**D24b**	**D24c**	**D24d**	**D25a**	**D25b**	**D25c**

4.7 Tomato production and loss during the last cropping and in 2018

4.7.1 What was your total tomato production net of pests' damages in **<u>all cropping in 2018</u>** (this include fruit consumed at <u>home before harvest</u>) **[D26] Quantity** [____] **Unit** [____]

4.7.2 What proportion of your tomato production (*post-harvest*) was lost due to all pests? [**D27]** [____]%

4.7.3 What proportion of production was lost (*post-harvest)* due to *Tuta absoluta*? [**D28]** [____]%

4.7.4 What proportion of production was lost due to diseases? **[D29]** [____]%

4.8 Utilization & Marketing of Tomato in <u>all cropping in 2018</u>

Cropping	Total production		Total quantity sold			Who bought ?	Total consumed at home		Gift/donation		Post-harvest loss		Who sold ?	Who make the decision to sell?	Who receives the money when sold?
	Qty	Unit	Qty	Unit	Price per unit		Qty	Unit	Qty	Unit	Qty	Unit			
D30	**D31a**	**D31b**	**D32a**	**D32b**	**D32c**	**D32d**	**D33a**	**D33b**	**D34a**	**D34b**	**D35a**	**D35b**	**D36**	**D37**	**D38**
1															

4.9 **Do you have a contract for Tomato production/ marketing? [D44] [_________] 1=Yes 0=NO**

4.10 Are you or any other household member currently a member of any tomato production and marketing association group [**D45]** [_________] **1.Yes 0.NO**

4.11 What is the cost of hiring casual laborer in your village (KES/day)____________Number of hours worked per day___________

MODULE 5: Willingness to Pay

5.1 **Willingness to Pay for A Biopesticide for Management Of Leaf Miner Pest (Tuta Absoluta)**

5.1.1 I would like to know your preferences (by ranking) with respect three production processes.

Table: pest control approaches/process

	Production approach 1 **(only chemical)**	**Production approach 2 (only biopesticides)**	**Production approach 3** **(Chemical + Biopesticides)**	**Production approach 4** **(none)**
Cost (per acre)	24,300 861,192	17,000 602,480	20,000 708,800	N/A
Efficacy	Effective	very effective	very effective	No effect on pests
Health impact	Very high health risks (through exposure, contaminate (food, and water)	No health risk	Reduce health risk by about 50%	No health risk
Loss of biodiversity	Leads very high loss of biodiversity (pollinators,	No risk to biodiversity	Reduce environmental risk by about 50%	No risk to biodiversity

Rank	Production process 1*	Production process 2	Production process 3	Production process 4
E24				

5.1.2 Given the above information, would you be interested in using the **Biopesticides** for management of leaf miner that affect your tomato production once it is introduced in the market? [**E25]** [__________] **0=No 1=Yes**;

5.1.3 If **NOT** interested in USING the biopesticide (**NO** in Qnr 5.4.2), give reasons for not willing? [**E26]**

5.1.4.1 Would you be willing to pay Ksh. **_____** [*cspro to pick the total cost of pesticides specifically targeting Tuta absoluta from 3.5.7 or 4.6.2)* for this Biopesticide that increases income and to avoid the risks pesticides poses to the human and environment health [**E26]** [**_________**] 0=No; 1= Yes. [*if **YES**, go to Q 5.1.4.2 and if **NO** go to Q 5.1.4.3]*

5.1.4.2 Premium: Would you be willing to pay Ksh. _____ for the Biopesticide that increases income and avoid the risks pesticides poses to the human and environment health? **[E26] [_________] 0=No; 1= Yes** [*if **NO**, go to 5.1.4.5; if **YES**, to 5.1.4.5]*

Change	+5%	+10%	+15%	+20%
price asked	Ksh.	Ksh.	Ksh.	Ksh.

5.1.4.3 Discount: Would you be willing to pay Ksh.**_____** for the Biopesticide that increases income and avoid the risks pesticides poses to the human and environment health? **[E26] [_________] 0=No; 1= Yes [***if **No** go to 5.1.4.4; if **Yes** go to 5.1.4.5]*

Change %	-5%	-10%	-15%	-20%
price asked	Ksh.	Ksh.	Ksh.	Ksh.

5.1.4.4 If **NO** in Qnr 5.4.4.1 & 5.4.4.3, why are you not willing to pay for the Biopesticide package ? [**E28]**

5.1.4.5 If YES in *Qnr 5.4.4.2 & 5.4.4.5* or *NO in Onr. 5.4.4.2,* how soon would you be willing to adopt the strategy [E32]

Time finished interview (24 HR) …………………….

Thank you very much for your time and participation

Appendix C: Publication abstract

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MDPI

Article

Knowledge, Attitude, and Practices on Tomato Leaf Miner, *Tuta absoluta* on Tomato and Potential Demand for Integrated Pest Management among Smallholder Farmers in Kenya and Uganda

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Abstract: Agricultural growth and food security are a priority in many developing countries. This has led to increased attention to effective pest management. Integrated Pest Management (IPM) strategy is a sustainable and recommended alternative to the use of synthetic pesticides in the management of tomato pests, with *Tuta absoluta* being the major one. This study seeks to assess the awareness, attitude, and control practices on *T. absoluta* and examine the potential adoption of a proposed IPM strategy for the management of a pest using a randomly selected sample of 316 and 345 tomato growing households in Kenya and Uganda, respectively. The study findings indicate that *T. absoluta* is the major pest affecting tomato production, with most farmers using synthetic pesticides to manage it. Furthermore, we find a significant proportion of the survey respondents willing to adopt the IPM strategy. The probability of adopting the strategy was positively related to a farmer being male, residing near a source of inputs, accessing training, and possessing good knowledge, attitude, and practices towards the use of non-pesticides strategies. Thus, training, promotion, and awareness creation of the *T. absoluta* IPM are recommended for the sustainable management of the pest in tomato production.

Keywords: Integrated Pest Management; *Tuta absoluta*; *ex-ante* adoption; bayesian analysis; Kenya; Uganda