IMPACT OF ADOPTION OF IMPROVED INTEGRATED PEST MANAGEMENT PRACTICES IN THE SUPPRESSION OF MANGO FRUIT FLY INFESTATION IN EMBU COUNTY KENYA

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other university.

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I would like to dedicate this thesis to my loving wife Dorsila Atieno and son Jeremy Conrad, parents Mr. John Wao and Mrs. Monica Atieno for their tireless encouragement, provision, and love in the course of my study.

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ABSTRACT

Fruit fly infestation is the most limiting constraint in mango production in Kenya. To enhance the suppression of this invasive pest, the International Centre of Insect Physiology and Ecology developed an auto-dissemination technique to be integrated into the existing integrated pest management (IPM) components. This study aimed to assess the impact of adopting the improved IPM in the suppression of mango fruit flies in Embu County using a two-period panel data. Using a Correlated Random Effects Probit Model to analyse the drivers of IPM adoption overtime, the study reports that the perceived quality of IPM enhances adoption of the technology. To assess the factors influencing dis-adoption of IPM, the study implemented a Discrete-time Proportional Hazard Model, and the results revealed that the perceived unavailability of the technology discourages the farmers from adoption. The study fitted a difference in difference (DiD) model to estimate the impact of integrating auto-dissemination with the conventional IPM on three outcome variables such as, mango net income, expenditure on pesticides and the proportion of post-harvest losses. Impact was differentiated by three treated groups of mango farmers; farmers treated with male annihilation technique (MAT), auto-dissemination technique farmers (ADT), MAT+ADT farmers and the control group. The combination technique (MAT + ADT) showed an increase net mango income of Kshs. 42,960 per acre, expenditure of pesticides decreased by Kshs. 7,226 per acre and proportion of post-harvest losses by 27.18% reduction. The study recommends integration of ADT into the existing conventional fruit fly IPM components to enhance the suppression of the invasive pest. In addition, IPM tailored-based training should be encouraged as a way of enhancing the adoption and preventing the dis-adoption of IPM technology.

Keywords: Mango, fruit fly, integrated pest management, auto-dissemination, impact

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ABBREVIATIONS AND ACRONYMS

ADB: Asian development bank

ADT: Auto-dissemination technique

CPHM: Cox-proportional hazard model

CREP: Correlated random effects probit

CSPro: Census and survey program system

DiD: Difference-in-difference

DPHM: Discrete-time proportional hazard model

FAO: Food and agriculture organization

FEL: Fixed effect logit

FPEAK: Fresh produce exporters association

FSD: Financial sector deepening

HCD: Horticultural development directorate

icipe: International Center of Insect Physiology and Ecology

IPM: Integrated pest management

MAT: Male annihilation technique

MAT+ADT: Male annihilation technique plus auto-dissemination techniqu

PSM: Propensity score matching

RE: Random effects

RSA: Research solutions Africa

SSA: Sub-Saharan Africa

CHAPTER ONE: INTRODUCTION

1.1 Background

Tropical fruits production such as mango contributes significantly to employment creation, income generation and to food and nutritional security globally, and in Sub-Saharan Africa (RSA, 2015; FAO and CIRAD, 2021; FPEAK, 2021). In Kenya mango is the second most important fruit after bananas in terms of the value of production (HCD 2017; Wangithi *et al*., 2021). The volume of mango produced in Kenya between 2005 and 2017 tripled from 254,113 tons to 772,700 tons making the country the third-largest producer in Africa (FSDK, 2015; FAO, 2022). The average gross domestic value of mango production in Kenya per year was estimated at USD 84.4 million (FAO, 2022). In addition, mango value chain contributes to employment creation and has been reported to have the potential to provide an additional 3.2 million employment opportunities in Kenya (CABE, 2022).

Despite the economic importance of mango in Kenya, production and marketing of the fruit are constrained by several factors (HCD, 2017). These factors include; pests and diseases infestations such as fruit flies and rust, high investment costs, low uptake of improved technologies, seasonal glut resulting in high post-harvest losses, and low bargaining power by smallholder farmers (HCD, 2017; UNIDO, 2020). Pest and diseases infestation is the most constraining factor due to the resulting economic losses such as limiting access to export markets due to sanitary and phytosanitary regulations (HDC, 2017;SNV, 2018;UNIDO, 2020).

Fruit flies are the most predominant pests in mango production due to the magnitude of the economic losses that they cause (Badii *et al*., 2015; Boulahia-Kheder, 2021). Fruit fly infestation attracts quarantine measures that prevent horticultural produce from accessing export markets, reducing foreign exchange earnings and farmers’ net income (Ekesi *et al*., 2016). In Kenya, fruit-fly infestation led to export ban of mango fruits in the 2014 -2021 period during which annual net mango revenue was reduced by more than USD110 million (Agrilinks, 2022). Mango losses attributed to fruit fly infestation account for more than 40 percent of all mango losses (Agrilinks, 2022). Further, farmers find it difficult to control fruit fly infestation because of the ecology of the pest as the pupa stage of these pests in the soil offers them protection from insecticides that are applied on the surface (Heve *et al*., 2017; Dias *et al*., 2018).

In an attempt to reduce mango fruit fly infestation, farmers often use broad-spectrum chemical pesticides (Mwungu *et al*., 2020). However, the conventional use of these pesticides is unsustainable because they are not only expensive especially to the smallholder farmers, but also pose negative risks to human health and the environment (Mwungu *et al*., 2020). Mango farmers are also using indigenous methods such as herbs and plant-based solutions which they perceive to be less costly and environmentally friendly, but are less effective in the control of the invasive pest (Wangithi *et al*., 2021). In response to these challenges by the two management methods, the International Center of Insect Physiology and Ecology (*icipe*) and its partners developed and promoted a fruit fly Integrated Pest Management (IPM) as a more effective and sustainable approach to the suppression of fruit flies (Ekesi *et al*., 2016).

IPM is a decision-based process involving the coordinated use of multiple tactics for optimizing the control of pests (Ehler, 2006). *icipe's* fruit fly IPM package consists of five components; male annihilation technique, spot spray of food bait, Metarhizium anisopliae-based bio-pesticide application, releases of the parasitoid, and use of orchard sanitation (Ekesi *et al*., 2016). The male annihilation technique (MAT) entails the use of pheromones combined with toxicants to reduce the male fruit fly population (Ekesi *et al*., 2016). Since immature female fruit flies require protein for their eggs to develop, they are attracted to food baits containing toxicants placed at specific locations in the orchard. Bio-pesticides are fungus-based formulations that target the fruit fly at the larva and emerging adult stages (Ekesi *et al*., 2016). The release of parasitoids is a biological control strategy where beneficial insects are introduced to feed on the mango fruit flies (Ekesi *et al*., 2016). Orchard sanitation comprises a number of practices including systematically collecting and disposing of all infested fruits found on trees and the ground (Ekesi *et al*., 2016).

The adoption of fruit fly IPM in mango production (defined in this study as the use of at least one of the five practices) is reported to directly and indirectly yield positive and significant benefits (Korir *et al*., 2015; Muriithi *et al*., 2016; Midingoyi *et al*., 2019). The major direct benefits are; reduced expenditure on pesticides, higher yields and income from mangoes, decrease in mango losses, and reduced negative effects on human health and the environment (Korir *et al*., 2015; Muriithi *et al*., 2016; Midingoyi *et al*., 2019;Nyang'au et al., 2020; Gichungi *et al*., 2021). Some of the indirect benefits are improved household diets and women's empowerment from higher incomes (Nyang'au et al., 2020; Gichungi *et al*., 2021). Dis-adoption of IPM on the other hand was defined as the choice of farmers to voluntarily stop using all the fruit fly IPM components that they had used in at least the last three mango production seasons (Wangithi *et al*., 2021). Sahin (2006) attributed technology dis-adoption to the emergence of superior technologies and the dissatisfaction of some farmers with the performance of specific IPM technologies.

In addition to the above conventional fruit fly IPM packages, *icipe* and partners recently developed and rolled out an auto-dissemination technique (ADT) to be integrated into the existing conventional components to improve the effectiveness of the strategy. Auto-dissemination is an ecologically based strategy where insects are used as smart and reliable conveyors of bio-pesticides (Pope *et al*., 2018). The technique involves attracting wild fruit fly males to stations baited with male-specific lures and fungal spores (Pope *et al*., 2018). Through mating and other social behaviors, they subsequently transfer the fungal spores to target habitats and counterparts (Pope *et al*., 2018).

1.2 Statement of the Research Problem

Even though a significant portion of the literature on technology adoption has focused on factors influencing adoption, there exists limited evidence on the factors influencing technology dis-adoption, since most studies have treated dis-adopters as non-adopters (Kabir and Rainis, 2015; Korir *et al*., 2015; Muriithi *et al*., 2020; Muriithi *et al*., 2021; Wangithi *et al*., 2021; Muriithi and Kabubo-Mariara, 2022). Similarly, there is limited information on fruit fly IPM dis-adoption. Wangithi *et al*. (2021) assessed the determinants of fruit fly IPM dis-adoption in Kenya using cross-sectional data, but did not fully examine the drivers of adoption or explore the dynamics of adoption.

These previous studies on fruit-fly IPM adoption (Kabir and Rainis, 2015; Korir *et al*., 2015; Allahyari *et al*., 2016; Muriithi *et al*., 2020; Muriithi *et al*., 2021; Wangithi *et al*., 2021; Muriithi and Kabubo-Mariara, 2022) have not considered IPM technology-specific factors such as cost of IPM, quality of IPM, and unavailability of IPM when assessing the determinants of adoption of the technology. In addition, they did not consider the partial, seasonal, or the scale of use of IPM technology even though they contribute to the understanding of the reasons for the different decisions made by IPM users.

Using three mango production seasons between the baseline and endline surveys (that is, 2019/2020, 2020/2021, and 2021/2022), continuous users of IPM were defined as farmers who used IPM in all the three production seasons while seasonal users, were farmers who used fruit fly IPM in one or two of the described seasons. In order to assess in terms of scale of use of IPM on their mango orchards, farmers were classified as partial-farm users or whole farm users of the technology. Whole-farm IPM users were farmers who used fruit fly traps (MAT) in their entire mango orchard, while partial-farm users were those that used the traps only in a section of their mango orchards.

Despite the reported economic benefits of fruit fly IPM, the impacts of the integration with an auto-dissemination technique are not documented. Although there are some reports on the use of the auto-dissemination technique in the control of diamond black moth, tick vectors, and malaria, the available literature on technology adoption barely covers the promotion of the technique among farmers (Vickers *et al*., 2004; Caputo *et al*., 2012; Lwetoijera *et al*., 2014; Weeks *et al*., 2020). Furthermore, the studies on the auto-dissemination technique reported were based on laboratory and mini field experiments. Most of them reported the economic benefits of fruit fly IPM with no special emphasis on the IPM technology-specific factors which would require estimation of conditional effects of the technology.

This study fills these gaps in literature by assessing the determinants of fruit fly IPM adoption, and, their dis-adoption. In addition, this study estimated the impact of integrating the auto-dissemination technique with the conventional fruit fly IPM in managing mango fruit fly infestation.

1.3 Purpose of the study

This study assessed the impact of adoption of improved integrated pest management practices in the suppression of mango fruit-fly infestation. The specific objectives of this study were;

i. To analyse the determinants of adoption and dis-adoption of integrated pest management practices in the suppression of mango fruit fly infestation: Evidence from Embu County, Kenya
ii. To assess the impact of adoption of improved integrated pest management practices in the suppression of mango fruit fly infestation in Embu County, Kenya.

This study tested two key hypotheses corresponding to each of the assessed specific objectives;

i. The perceived benefits of IPM do not influence fruit fly IPM adoption and dis-adoption
ii. Integrating ADT with conventional IPM has no impact on mango net income, expenditure on pesticides, and on the proportion of post-harvest losses

1.4 Justification

Information on the determinants of IPM dis-adoption is useful to extension officers, policymakers, traders of IPM technology, and researchers in order to create awareness and promote IPM considering the documented economic benefits of the technology. The information on the impact of integrating ADT with the conventional IPM is necessary for the promoters of the new technique, policy makers, traders and farmers. This study contributes to Kenya's Agricultural Sector Development Strategy focusing on pest control. It is aligned to Kenya’s Migratory and Invasive Pests and Weeds Management Strategy (2022-2027) that seeks to establish a modern information and knowledge management system to strengthen surveillance, forecasting and ensure timely and effective control operations.

The study is in line with the Strategy for Agricultural Transformation in Africa (2016-2025) aimed at improving agricultural productivity through large scale dissemination of productivity raising technology. In addition, the study is in line with Africa's Agenda 2063 aspiration on modernizing agriculture to improve productivity through science, technology, and innovation.

Further, the study contributes to Sustainable Development Goals numbers 2, 3, 12, and 13 on end hunger, achieve food security and improved nutrition and promote sustainable agriculture, good health, sustainable production and climate change concerns. Finally, information generated from this study contributes to the growing body of knowledge on technology adoption and dis-adoption, and impact assessment particularly focusing on mango production and fruit fly IPM.

1.5 Organization of the thesis

This thesis is organized in paper format. Chapter 1 presents the detailed background of the study, statement of the research problem, objectives of the study, hypotheses tested, and justification of the study while chapter 2 presents a review of the literature on mango production, fruit flies, IPM, adoption and impact studies on IPM. Chapter 3 presents the first paper entitled ‘‘Determinants of adoption and dis-adoption of integrated pest management practices in the suppression of mango fruit fly infestation: Evidence from Embu County, Kenya’’ while chapter 4 contains the second paper entitled ‘‘Impact of adoption of improved integrated pest management practices in the suppression of mango fruit fly infestation in Embu County, Kenya’’. Chapter 5 presents general conclusions and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Mango production

Mango production has been increasing globally between 2008-2018 period from 36,182.5 thousand tons to 52,084.1 thousand tons (FAO, 2018). Similarly, production of mangoes in Africa also increased from 3958.3 thousand tons in 2008 to 8209.1 thousand tons in 2018 (FAO, 2018). In Kenya, mango is the second ranked fruit after bananas in terms of value and quantities produced and, contributes significantly to the country's Agricultural Domestic Product (RSA 2015; HCD, 2017). Kenya is the third-largest producer of mango fruits in Africa in terms of volume and area under production with an estimated increase from 448.6 thousand tons in 2008 to 745.9 thousand tons in 2018 (FAO, 2018). Horticultural Crops Directorate (2017) reported an estimated area under mango production of 50,550 ha, a 3 percent increase in 2017 from the previous year.

Mango export is reported to have increased in the world between 2008 and 2018 from 1010.6 thousand tons to 1601.3 thousand tons (FAO, 2018). In Africa, the estimated increase between 2008 and 2018 according to FAO (2018) is from 73.4 thousand tons to 117.9 thousand tons. Kenya mainly exports its mangoes to United Arab Emirates, Saudi Arabia, and other Middle Eastern countries(KALRO, 2019;Tridge, 2019). Mango export in the country has seen a steady increase between 2008 and 2018 from 8.2 thousand tons to 12.7 thousand tons (FAO, 2018).

2.1.1 Constraints and opportunities in mango production

Mango production faces constraints that hamper production such as adverse and severely disruptive weather conditions, irrigation water scarcity, access to skilled labor, access to credit, and pests and diseases (Micah and Inkoom, 2016; FAO, 2018). In addition, access to extension services, unavailability of storage facilities, and acquisition of fertilizers, and the incidence of fruit dropping have also been reported to have a direct effect on the profit margin of mango farmers(Micah and Inkoom, 2016). Verma *et al*. (2018)reported susceptibility of diseases and insect pests as the main constraints to mango production followed by inadequate knowledge of scientific cultivation practices.

In Kenya, fruit flies are reported to be the main constraining factor in mango production (Badii *et al*., 2015). This invasive pest is considered a quarantine pest in the export market thereby limiting Kenya's mango fruits from accessing the European Union markets (Badii *et al*., 2015; SNV, 2018). Fruit flies belong to the family of Tephritidae and their management is not easy due to their ecology (Heve *et al*., 2017). Their pupa in the soil protects them from the broad-spectrum chemicals that are applied on the surface (Heve *et al*., 2017).

To overcome these constraints in mango production, Micah and Inkoom (2016) proposed an integrated agro-industrial development framework that is centered on micro-enterprise and public-private partnership policies. Dealing with weather-related supply disruptions calls for mango-producing countries to increase the area under mango production (FAO, 2017). Strategies for controlling mango fruit flies include the use of synthetic pesticides which have been reported to have cost implications and negative effects on human health and the environment and (Korir *et al*., 2015; Mwungu *et al*., 2020). *icipe* and other collaborating partners have also developed and encouraged the adoption of a fruit fly IPM to address the challenges highlighted in the management of mango fruit flies (Ekesi *et al*., 2016).

Addressing the reported constraints in mango production present opportunities for the country to upscale production, increase export quantities and extend export outlets to the untapped markets like Netherlands and Germany (Tridge, 2019). Moreover, opportunities exist for increasing mango production due to the growing global demand for mangoes in response to increased demand for fresh markets, access to fruits processing facilities, and more informed health concerns (HCD, 2017).

2.2 The concepts of integrated pest management and auto-dissemination

2.2.1 Integrated Pest Management

Integrated pest management is a pest control strategy which is defined as a set of steps taken to avoid, reduce or delay the impact of pests on crops (Prokopy and Kogan, 2009). Integrated control as a concept was aimed at combining and integrating biological and chemical control methods (Prokopy and Kogan, 2009). Dent (1995) defined IPM as a system that utilizes all suitable techniques in a compatible manner to maintain the pest populations below economic injury levels. The main goal of IPM according to Dent (1995) was to provide farmers with an economic and appropriate means of controlling pests.

Pest management over the years has been dependent on the use of synthetic pesticides which have been reported to result in insecticide-resistant pests and, negative environmental and human health effects such as loss of biodiversity, pollution of soils and water resources (Bottrell and Quality, 1979). Due to the emergence of insecticide-resistant pests and a declining availability of active substances, the future of crop production is threatened (Barzman *et al*., 2015). Therefore, it became indispensable for a system that would respond to the problems associated with the synthetic pesticides to be developed leading to the emergence of the IPM concept (Prokopy and Kogan, 2009).

2.2.2 Auto-dissemination technique

Auto-dissemination involves the attraction of male insects into specially designed inoculation chambers in response to synthetic female sex pheromone (Vickers *et al*., 2004). Lwetoijera *et al*. (2014) reported that the use of insecticides to control malaria vectors became ineffective due to the emergence of insecticide-resistant vectors, therefore, auto-dissemination techniques were embellished to counter the challenges of malaria vector insecticides. In addition, Weeks *et al*. (2020) reported the emergence of acaricide-resistant ticks further necessitating the use of auto-dissemination. The use of auto-dissemination technique to transfer malaria control vectors proved to be significant with higher mortality rates of 50-70% reported (Caputo *et al*., 2012).

2.2.3 *icipe's* IPM and Auto-dissemination Interventions

The International Centre of Insect Physiology and Ecology developed an IPM strategy to be used in suppression of fruit flies (Githiomi *et al*., 2019). This strategy was promoted as a more sustainable approach in addressing the limitations of the primary use of synthetic pesticides and farmers' indigenous methods in controlling the invasive pest (Githiomi *et al*., 2019). The fruit fly IPM package consists of five different components namely; spot spray of food bait, male annihilation technique, Metarhizium anisopliae-based bio-pesticide application, releases of the parasitoid, and use of orchard sanitation (Korir *et al*., 2015; Muriithi *et al*., 2016). Male annihilation technique (MAT) entails the use of male attractant combined with a toxicant to reduce fruit fly males population, food bait is applied as localized spots where adult male and female fruit flies are attracted to and ingest the toxicant, bio-pesticides are fungus-based formulations that target larval stages of the fruit flies and emerging adults and orchard sanitation entails systematic collection and destruction of all infested fruits found on trees and fallen fruits on the ground (Ekesi *et al*., 2016; Muriithi *et al*., 2016).

The *icipe's* auto-dissemination technique is a product of pest-free fruit project whose goal is to develop and promote cost-effective and system-wide bio-control strategies that contributes to the intensification of fruit production systems. The bio-control strategies include methods that are based on the use of living organisms as a sustainable way of reducing the use of synthetic pesticides and without negative environmental impact. Auto-dissemination is a technique where insects are used as smart conveyors of bio-pesticides through social behaviors (Pope *et al*., 2018). This technique has been developed to complement and enhance the effectiveness of the conventional IPM package.

2.3 Literature on fruit fly IPM adoption

The empirical evidence on the potential adoption of the fruit fly IPM, willingness to pay for IPM products as well as ex-post adoption of the technology is well documented (Korir *et al*., 2015; Allahyari *et al*., 2016; Muriithi *et al*., 2020;Muriithi *et al*., 2021;Wangithi *et al*., 2021). In evaluating the factors influencing the uptake of olive fruit fly IPM in Iran, Allahyari *et al*.(2016) used descriptive statistics to analyse cross-section data drawn from 171 olive growers. Findings from this study by Allahyari *et al.* (2016) show a statistically significant relationship between growers' annual income, land area under cultivation, farming experience, extension activities, technical knowledge, and average olive fruit production and the adoption rates of fruit fly IPM.

This study by Allahyari *et al*. (2016) however, did not proceed to the empirical analysis of the relationships.

Muriithi *et al*. (2020) applied a multinomial logit model in assessing the potential adoption of IPM in the suppression of fruit flies in Kenya and Ethiopia. This study, however, did not consider the potential dis-adoption of fruit fly IPM. In addition, Korir *et al*. (2015) also fitted a negative binomial regression model to assess the grower adoption of the different packages of fruit fly IPM. The authors, just like Muriithi *et al*. (2020) treated dis-adopters as non-adopters and did not consider the likelihood of fruit fly IPM dis-adoption in the near future.

Wangithi *et al*. (2021) evaluated the determinants of fruit fly IPM adoption and dis-adoption. Using a multinomial logit, the study report factors such as training attendance, education of the household head, and contact with extension officer that significantly influenced the adoption and dis-adoption of fruit fly IPM. This study, however, did not exhaust the IPM technology-specific factors including cost of IPM, quality of IPM, and unavailability of IPM which are considered to be important drivers of fruit fly IPM adoption.

Different adoption categories of fruit fly IPM adoption reported by Wangithi *et al*. (2021) included the descriptive comparison of fruit fly IPM non-adopters, adaptors, and dis-adopters and, the use of different control strategies such as farmers' innovations and synthetic pesticides for the invasive pest. The authors, however, did not fully explore the categories of adoption within the fruit fly IPM adoption profile. The adoption categories not covered include the classification of IPM adopters with respect to the scale of IPM use in mango orchards, whether farmers are seasonal or continuous users of IPM, and, the use of panel data to report the status of adoption and dis-adoption of IPM. According to Wangithi *et al*. (2021), exit from adoption was reported to be correlated with mango farm size and the education of the household head in controlling the invasive pest. The study by Wangithi *et al*. (2021) provides the baseline data for this study.

These foregoing previous literature on fruit fly IPM adoption and dis-adoption were predicated on the use of cross-section data, therefore, making it difficult to control for unobserved individual heterogeneity. Second, these studies did not include IPM technology-specific factors such as cost of IPM, quality of IPM, and unavailability of IPM as adoption constraints when assessing the determinants of IPM adoption. Lastly, there is limited evidence on the determinants of fruit fly IPM dis-adoption. To fill the gaps, this study utilized two-period panel data and included fruit fly IPM technology-specific factors in the models of adoption and dis-adoption.

2.4 Empirical studies on the impact of fruit fly IPM

The empirical literature on the impact of the adoption of IPM point to the positive effects of the technology (Rakshit *et al*.,2011; Kibira *et al*.,2015; Muriithi *et al*.,2016; Githiomi *et al*.,2019; Midingoyi *et al*.,2019; Nyang'au *et al*.,2020; Gichungi *et al*.,2021). Rakshit *et al*. (2011) assessed the economic impact of pheromone traps in managing fruit flies on sweet gourd cultivation in Bangladesh. The study utilized an economic surplus model where shifts in supply and demand curves were projected based on changes in yield due to reduced pest damage, changes in input costs, and technology adoption. The estimated results indicated that the adoption of IPM generated substantial economic benefits. The study by Rakshit *et al*. (2011) however, focused on projections of market-level benefits of the technology and ignored farm-level benefits of IPM and, the model used was not suitable for dealing with selection bias.

Islam *et al*. (2018) evaluated the economic impact of IPM technology in bitter gourd production in Bangladesh and reported that farmers had favorable attitudes towards IPM with adopters achieving higher profits than non-adopters. However, the use of descriptive statistics is insufficient in modeling adoption since it cannot be used to test hypotheses and does not control for unobserved individual heterogeneity and selection bias.

Kibira *et al*. (2015) assessed the impact of IPM adoption on farmers' expenditure on synthetic pesticides using a difference in difference (DiD) method and reported a decline in this expenditure. Similarly, Muriithi *et al*. (2016) employed a DiD model to report the significant impacts of IPM adoption on different outcome variables including a reduction in the quantity of mango rejected and increased net mango income in Kenya. Githiomi *et al*., (2019) analysed the spill-over effects of IPM technology adoption on four fruit crops (avocado, citrus, pawpaw, and banana) in Meru County. The study fitted a regression model that used the propensity score matching method to determine the cross-commodity effect of IPM. The study reported that the use of IPM in controlling mango fruit flies positively affected the gross margins for pawpaw and citrus.

Midingoyi *et al*. (2019) estimated the impacts of the different fruit fly IPM components on the yield of mango, net income from mango, insecticide expenditure, the environment, and on human health. Results from the endogenous switching regression model indicated that the adoption of IPM components leads to higher mango yields, higher mango net income, and suppressed use of insecticides. In addition, evidence from a study conducted in Meru County, Kenya on environmental and human health impacts of fruit fly IPM shows that the adoption of the technology leads to a reduction in pesticide use and toxicity (Mwungu *et al*., 2020). The current study sought to extend these studies by utilizing panel data for the newly developed component of fruit fly IPM.

Nyang'au *et al*. (2020) evaluated the impact of the IPM strategy on food security in Machakos County, Kenya using the DiD method. The results of the study suggested that adopters of fruit fly IPM technology benefit from income gains which consequently leads to an improved quantity of food consumed but not the diversity of the foods. Using a sample of 470 mango growers from Machakos County, Kenya, Gichungi *et al*.(2021) assessed the effect of technological innovation on gender roles. The study employed a two-limit Tobit difference-in-differences model on the women's decision-making index to provide empirical evidence on the impact of a fruit fly IPM technology adoption on intra-household decision-making in mango production, as well as marketing activities.

The limited literature on the auto-dissemination technique has reported its impact on the control of diamond black moth and on, malaria and tick vectors (Vickers *et al*., 2004; Caputo *et al*., 2012; Lwetoijera *et al*., 2014; Weeks *et al*., 2020). Vickers *et al*. (2004) assessed the effect of the auto-dissemination technique in the control of diamond black and, the findings suggest that the technique is effective in managing the diamond black moth population. In addition, the use of the auto-dissemination technique aids in the suppression of the mosquito population (Caputo *et al*., 2012; Lwetoijera *et al*., 2014). Further, Weeks *et al*. (2020) analyzed the effect of the auto-dissemination technique in controlling tick vectors, the findings show that the treated ticks disseminated the fungal pathogens to untreated ticks increasing the mortality rates of the vector. These studies were, however, based on laboratory and field experiments and, did not measure the economic benefits of the technique using econometric methods.

These previous studies did not exhaust IPM technology-specific factors when assessing the impacts of the technology. Second, the previous studies on auto-dissemination techniques were based on laboratory and field experiments. In addition, the studies on auto-dissemination techniques were limited to the control of diamond black moths and the control of tick and malaria vectors. Further, the impact of integrating the auto-dissemination technique into the existing conventional IPM is yet to be documented. To fill the gaps, this study evaluated the economic impact of integrating the auto-dissemination technique with the conventional IPM. The impact is disaggregated by three treatments and a control group and, measured on three outcome variables.

CHAPTER THREE: DETERMINANTS OF ADOPTION AND DIS-ADOPTION OF INTEGRATED PEST MANAGEMENT PRACTICES IN THE SUPPRESSION OF MANGO FRUIT FLY INFESTATION: EVIDENCE FROM EMBU COUNTY, KENYA

Abstract

This study evaluated the drivers of the adoption and dis-adoption of Integrated Pest Management (IPM) practices in the suppression of mango fruit-fly infestation. It employed a Correlated Random Effects Probit Model and a Discrete-time Proportional Hazard Model on a two-wave panel data of 149 mango farmers from Embu County, Kenya selected using a cluster sampling technique. The descriptive results show that 59 and 17 percent of the respondents were adopters and dis-adopters of the mango fruit fly IPM practices respectively. Empirical findings reveal that the cost of IPM and training on IPM positively and significantly influenced adoption while the unavailability of the technology had a negative and significant effect on adoption. For dis-adoption, the results indicate that farm size and the quality of IPM positively influenced the hazard of exit from IPM use and hence enhanced the sustained adoption of IPM. The study recommends capacity building for mango farmers through training and increased access to extension services to enhance the adoption of this technology and prevent dis-adoption.

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3.1 Introduction

Fruit flies are considered the most important pests in the horticulture sector, not only in Sub-Saharan Africa (SSA) but also in other parts of the world (Badii *et al*., 2015; Boulahia-Kheder, 2021). In particular, they are the most predominant pests in mango production due to the magnitude of the economic losses that they cause (Badii *et al*., 2015; Boulahia-Kheder, 2021). Fruit fly infestation attracts quarantine measures that prevent horticultural produce from accessing export markets, reducing foreign exchange earnings and farmers' net income (Ekesi *et al*., 2016). In Africa, total annual losses in mango production are estimated at USD 2 billion, 40% of which are due to fruit fly infestation (Ekesi *et al*., 2016). In Kenya, farmers find it difficult to control fruit fly infestation because of the ecology of the pest constraint (Heve *et al*., 2017). The pupa stage of these pests in the soil offers them protection from insecticides that are applied on the surface (Dias *et al*., 2018).

For many years in Kenya, mango farmers have relied on the conventional use of synthetic pesticides to control fruit flies. (Midingoyi *et al*., 2019). However, the method is, unsustainable because synthetic pesticides are not only expensive but they also pose negative risks to human health and the environment (Mwungu *et al*., 2020). Historically, farmers have also used indigenous control methods which they consider more cost-effective and environmentally friendly but less effective, such as "smoking herbs" (Wangithi *et al*., 2021). In response to these challenges, the International Center for Insect Physiology and Ecology (*icipe*), and other partners have developed and promoted an Integrated Pest Management (IPM) package as a more sustainable approach to managing mango fruit-fly infestation over the last decade (Ekesi *et al*., 2016).

IPM is a decision-based process involving the coordinated use of multiple different techniques to effectively manage pests (Ehler, 2006). *icipe's* fruit fly IPM package consists of five components; male annihilation technique, spot spray of food bait, Metarhizium anisopliae-based bio-pesticide application, releases of the parasitoid, and use of orchard sanitation (Ehler, 2006; Korir *et al*., 2015). The male annihilation technique (MAT) entails the use of pheromones combined with toxicants to reduce the male fruit fly population (Ekesi *et al*., 2016). Since immature female fruit flies require protein for their eggs to develop, they are attracted to food baits containing toxicants placed at specific locations in the orchard. Bio-pesticides are fungus-based formulations that target the fruit fly at the larva and emerging adult stages (Ekesi *et al*., 2016). The release of parasitoids is a biological control strategy where beneficial insects are introduced to feed on the mango fruit flies (Ekesi *et al*., 2016). Orchard sanitation comprises a number of practices including systematically collecting and disposing of all infested fruits found on trees and the ground (Ekesi *et al*., 2016).

The adoption of fruit fly IPM in mango production (defined in this study as the use of at least one of the five practices) has been reported to both directly and indirectly yield positive and significant benefits (Korir *et al*., 2015; Muriithi *et al*., 2016; Midingoyi *et al*., 2019;Nyang'au *et al*., 2020; Gichungi *et al*., 2021). The major direct benefits are; reduced expenditure on pesticides, higher yields and income from mangoes, decrease in mango losses, and reduced negative effects on human health and the environment (Korir *et al*., 2015; Muriithi *et al*., 2016; Midingoyi *et al*., 2019). Some of the indirect benefits are improved household diets and women's empowerment from higher incomes (Nyang'au *et al*., 2020; Gichungi *et al*., 2021).

In spite of the direct and indirect benefits from the adoption of f of fruit-fly IPM, it has been found that some farmers make the decision to dis-adopt the technology (Wangithi *et al*., 2021). In this study, the dis-adoption of IPM is defined as the choice of farmers to voluntarily stop using all the fruit fly IPM components that they had used in at least the last three mango production seasons (Wangithi *et al*., 2021). In addition to dis-adoption, it has also been observed that adoption of fruit-fly IPM technology is slow (Kabir and Rainis, 2015; Korir *et al*., 2015; ; Muriithi *et al*., 2021; Wangithi *et al*., 2021).

Some of the factors which have been shown to explain variation in the adoption of fruit fly IPM among farmers are; technology-specific characteristics such as cost and unavailability, farm and farmer characteristics particularly s education of the household head, household size, training, farm size, and membership to groups related to mango production (Kabir and Rainis, 2015; Korir *et al*., 2015; ; Muriithi *et al*., 2021; Wangithi *et al*., 2021). On the other hand, variation in dis-adoption of the technology is explained by the unavailability of the required inputs in the market and their high cost (Wangithi et al., 2021). Sahin (2006) attributes technology dis-adoption to the emergence of superior technologies and the dissatisfaction of some farmers with the performance of specific IPM technologies. While these past studies provide useful insights into IPM adoption, they do not consider the partial, seasonal, or the scale of use of IPM technology.

Using three mango production seasons between the baseline and endline surveys (that is, 2019/2020, 2020/2021, and 2021/2022), continuous users of IPM were defined in this study as farmers who used IPM in all the three production seasons while seasonal users, were farmers who used fruit fly IPM in one or two of the described seasons. In order to assess in terms of scale of use of IPM on their mango orchards, farmers were classified as partial farm users or whole farm users of the technology. Whole-farm IPM users were farmers who used fruit fly traps (MAT) in their entire mango orchard, while partial-farm users were those that used the traps only in a section of their mango orchards. Seasonality and scale of use have not been evaluated in previous studies on fruit fly IPM, even though they contribute to the understanding of the reasons for the different decisions made by IPM users.

Even though a significant portion of the literature on technology adoption has focused on factors influencing adoption, there exists limited evidence on the factors influencing technology dis-adoption, since most studies have treated dis-adopters as non-adopters (Kabir and Rainis, 2015; Korir *et al*., 2015; ; Muriithi *et al*., 2021; Wangithi *et al*., 2021; Muriithi and Kabubo-Mariara, 2022). Similarly, there is limited information on fruit fly IPM dis-adoption. Wangithi *et al*. (2021) assessed the determinants of fruit fly IPM dis-adoption in Kenya using cross-sectional data, but did not fully examine the drivers of adoption or explore the dynamics of adoption. In addition, the previous studies on fruit fly IPM adoption (Kabir and Rainis, 2015; Korir *et al*., 2015; Allahyari *et al*., 2016; ; Muriithi *et al*., 2021; Wangithi *et al*., 2021; Muriithi and Kabubo-Mariara, 2022) did not consider IPM technology-specific factors such as cost of IPM, quality of IPM, and unavailability of IPM when assessing the determinants of adoption of the technology. This study fills these gaps by assessing the determinants of fruit fly IPM adoption, as well as their dis-adoption using duration analysis. In addition, we test the hypothesis that "the perceived benefits of IPM technology do not influence adoption and dis-adoption of the technology".

3.2 Study Methods

3.2.1 Theoretical Framework and Empirical Approach

The decision to adopt or dis-adopt an IPM technology in this study is modelled following the random utility theory which posits that decision-makers are rational and will seek to maximize utility based on the available choices (Cascetta, 2009). Farmers facing a set of available alternatives will choose the alternative that maximizes their utility (Baltas and Doyle, 2001). Following Greene(2002), the utility function for the adoption of mango fruit fly control IPM technology was specified as follows:

$$U^{a} = X' \beta_{ipm} + \varepsilon_{ipm} \quad (3.1)$$

$$U^{n} = X' \beta_{ipm} + \varepsilon_{ipm} \quad (3.2)$$

where; U^{a} is the utility derived from adopting the mango fruit fly IPM strategy; U^{n} is the utility derived by the farmers using alternative control strategies such as synthetic pesticides and indigenous methods. β are the parameter estimates and ε is the error term. Subsequently, the observed measure of adoption equals one (1) if $U^{a} > U^{n}$ and equals zero (0) otherwise.

When the utility of adopting IPM diminishes, farmers discontinue the use of this technology (Jenkins, 1995). Following the random utility theory, we assume that farmers choose to adopt the IPM technology because of the higher benefits they derive from the adoption of IPM technology and they choose not to adopt based on the benefits they derive from using other strategies such as synthetic pesticides and indigenous methods in managing mango fruit flies.

Assessment of the determinants of technology adoption is guided by the nature of the dependent variable. In cases where discrete choice is made, a Probit or Logit model is used depending on whether a normal or a logistic distribution is appropriate (Muriithi *et al*., 2020). Multinomial logit is used in cases where the dependent variable has many choices (Wangithi *et al*., 2021). Other models used are the negative binomial regression, logistic regression, and Poisson (Korir *et al*., 2015; Muriithi and Kabubo-Mariara, 2022). These models use cross-sectional data and are not suitable for the current study, which uses panel data.

The decision to adopt fruit fly IPM over time can be modelled using binary choice panel data estimators such as Fixed Effects Logit Model (FEL) and a Correlated Random Effects Probit Model (CREP) (Alem *et al*., 2014). The fixed effects logit model is based on a within transformation that would drop any time-constant explanatory variables such as distance to the input market and farm size, and, on variations in the dependent variable over time, which would reduce the number of observations to be used for estimation (Stammann *et al*., 2016). Due to these limitations of a fixed effects logit model, the correlated random effects probit model was used.

The decision by farmers to dis-adopt IPM technology can be modelled using duration analysis models that such as Cox Proportional Hazard Model (CPHM) and the Discrete-time Proportional Hazard Model (DPHM) (Jenkins, 1995). Duration analysis is concerned with the timing of events where the event variable represents the transition from one state to another for instance from adoption to dis-adoption of IPM (An and Butler, 2012). The CPHM model is based on a continuous time analysis and cannot deal with unobserved individual heterogeneity such as mango farmers' skills and motivation. Thus it was not appropriate for the current study because the duration between adoption to dis-adoption of fruit fly IPM is characterized by discrete distribution and not continuous distribution (An and Butler, 2012; Khataza *et al*., 2018).

The Correlated Random Effects Probit was used to model mango farmers' decision to adopt IPM technology. The model is appropriate for use in panel data as it can be used to test the random effects (RE) assumption that heterogeneity such as mango farmers' skills and motivation is independent of time-varying covariates for example age, education of the household, and household size (Alem *et al*., 2014). Following Alem *et al*. (2014), the latent benefit of IPM adoption was specified as follows;

$$n_{it}^{*} = X'_{it}\beta + \varepsilon_{it} \quad i=1,2\ldots N;\ t=1\ldots T \tag{3.3}$$

$$\varepsilon_{it} = \alpha_i + \mu_{it} \tag{3.4}$$

$$n_{it} = \begin{cases} 1 & \text{if } n_{it}^{*} > 0 \\ 0 & \text{if } n_{it}^{*} \leq 0 \end{cases} \tag{3.5}$$

where n_{it}^{*} is the latent dependent variable; X_{it} is a vector of time-variant and time-invariant variables such as age and gender; β is a vector of parameters to be estimated; ε_{it} is the composite error term; α_i unobserved individual heterogeneity; μ_{it} the random error term; n_{it} is the observed binary outcome variable showing the adoption of fruit fly IPM; i and t are the smallholder mango farmers and periods respectively.

In estimating the parameters, the unobserved individual heterogeneity (α_i) such as mango farmers' motivation and skills were assumed to be correlated with the observable variables (X_{it}) and time (Mundlak, 1978). The transformation is made on the unobserved individual heterogeneity term in Equation (3.4) and the averages of independent variables were generated and included as additional regressors

$$\alpha_i = \varphi + \overline{X_i}\epsilon + a_i, a_i/\sim N(0, \delta_a^2) \tag{3.6}$$

where $\overline{X}_i$ is the average time-varying variable in X_{it}; δ_a^2 is the variance of unobserved individual heterogeneity (α_i).

To model the decision to dis-adopt IPM technology, the Discrete-time Proportional Hazard Model was used. The model is used in duration analysis in evaluating factors that have a significant effect (both positive and negative) on the hazard of exit from adoption and entry into dis-adoption (Burton *et al*., 2003).

The hazard rate represents the risk of exit from adoption to dis-adoption in the current study and, shows the proportion of households remaining in the adoption state at the time of observation (Jenkins 1995; Alem *et al*., 2014). Jenkins (1995) specifies the discrete-time hazard rate h_{it} as;

$$h_{it} = \text{prob}(T_i = \frac{t}{T_i} \geq t;\ X_{it}) \tag{3.7}$$

Where; T_i is a discrete random variable representing the time at which adoption duration ends; X_{it} represents a vector of explanatory variables (Jenkins, 1995). The proportional hazard specified by Jenkins (Jenkins, 1995) was used to analyze IPM adoption as follows;

$$h_{it} = h_0(t)\exp\left(X'_{it}\beta\right) \tag{3.8}$$

where h_{it}= pr(y_{it}=1/X_{it}); y_{it} =1 if a farmer dis-adopts IPM at time t; h_{it} is the hazard rate of adoption; $h_0(t)$ is the baseline hazard function which is common to all farmers within the sample (Alem *et al*., 2014); X'_{it} is the vector of regressors; β is the vector of parameter estimates. The exponential specification of the hazard function is adopted since the form ensures that the hazard function is non-negative without imposing restrictions on β coefficients. In addition, it facilitates interpretation of the results as the estimated β coefficients shows the direction and magnitude of influence of the covariates on the hazard rate (Khataza *et al*., 2018). To control for the unobserved individual heterogeneity, a random error term that is assumed not to be correlated with any of the regressors is multiplicatively introduced into the model in Equation (3.8) as shown below (Jenkins, 1995).

$$\mathrm{h_{it}} = \mathrm{h_0(t)\vartheta_i exp\ (=h_0(t)exp\ [X'_{it} + log\ (\vartheta_i)]} \quad (3.9)$$

Consequently, the discrete-time function in the *j*th interval that is in concordance with equation 10 above is specified as follows;

$$h_j\left(X'_{ij}\right) = 1 - \exp\left[-\exp\left(X'_{ij}\beta\right) + \gamma_j + \log\left(\vartheta_i\right)\right] \quad (3.10)$$

γ_j ; The parameter of the baseline hazard.

3.2.2 Definition and measurement of variables

The use of the male annihilation technique (MAT) was applied in the current study as a proxy for fruit fly IPM adoption as it is the most commonly used and commercialized component of the IPM package and generates significant benefits when used by itself (Wangithi *et al*., 2021). The variable was specified as a dummy variable; a farmer using MAT was assigned one and zero otherwise for the adoption model, while one who used the technology before and stopped was assigned one and zero otherwise in the dis-adoption model (Table 3.1).

The choice for independent variables included in the adoption and dis-adoption models was informed by literature on agricultural technology adoption and particularly, the adoption of fruit fly IPM and, in the context of this study (Kabir and Rainis, 2015; Korir *et al*., 2015; Allahyari *et al*., 2016; ; Muriithi *et al*., 2021; Wangithi *et al*., 2021; Muriithi and Kabubo-Mariara, 2022), includes demographic characteristics, household resources, access to information, social capital and networking and technology attributes.

Table 3.1:Description of variables used in the Correlated Random Effects Probit and Discrete-time Proportional Hazard Models

Dependent Variable	Definition and Measurement		
IPM Adoption	Are you currently/in the previous mango season used the male annihilation technique; 1=yes, 0=No		
IPM Dis-adoption	If not using/did not use the male annihilation technique in the previous mango season, were you using and stopped? 1=yes, 0=No		
Independent Variables	Definition and Measurement	Expected Sign	
		Adoption	Dis-adoption
Household demographic characteristics			
Gender of household head	Gender of household head (1 = male 0 = Female	−/+	−/+
Size of household	Household size in count	−/+	−/+
Education of household head	Number of schooling years of the household head	+	-
Age of household head	Age of the household head in years	−/+	−/+
Household resources			
Farm size	Total owned land in Acres	+	-/+
Farm income	Proportion of farm income out of total annual household income (%) for the last 12 months	+	-
Market and institutional information access			
IPM training	Attended training on Fruit Fly Integrated Pest Management (1 = yes, 0 = No)	+	-
Distance to input market	Minutes taken by a farmer to walk to the nearest source of input market	-	+
Contact extension officer	Visited by an extension officer in the last 12 months1=yes, 0= No	+	-
Social capital			
Mango group membership	Membership in a mango production/marketing group (1 = Yes, 0 = No)	+	-
Access to credit services	Accessed agricultural credit services in the last 12 months (1=yes, 0=No)	+	-
Fruit fly IPM attributes			
Unavailability of IPM technology	Whether unavailability of male annihilation technique is a constraint to its adoption (1=yes, 0=No	-	+
Cost of IPM technology	Whether cost of male annihilation technique is a constraint in adoption (1=yes, 0=No)	-	+
Quality of IPM technology	Whether quality of male annihilation technique is a constraint in adoption (1=yes, 0=No)	-	+

The gender influences the decisions made regarding resource allocation on the farm. Male-headed households are perceived to have more access to resources than female-headed households. Measured as a dummy (1=Male, 0=Female) variable, gender was hypothesized to have a positive effect on adoption and a negative effect on the dis-adoption of IPM. The size of the household was measured as the total count of persons who live and eat together from the same pot (share food). The size of the household among rural communities is often related to labour availability for agricultural activities, with bigger households more likely to adopt labour-intensive technologies. Education of the household head was measured as the total number of years of formal education.

Education is used as a proxy for human capital and technical skills and is associated with more awareness of the benefits of agricultural innovations and a greater ability to interpret new information to address production constraints (Pender and Alemu, 2007). In this study, therefore, education was hypothesized to have a positive influence on the adoption of IPM and an opposite influence on the dis-adoption of the technology. The direction of influence of the age of the household head is indeterminate on both the adoption and dis-adoption of IPM. While age is associated with more years of farming experience and therefore more likelihood of adopting an innovation, it is also correlated with risk averseness that may hinder the adoption of the innovation.

Two proxies for household resources- farm size and income were used. Larger farmsizes are associated with a higher probability of adopting new technologies (Kehinde, 2017). Consequently, farm size was hypothesized to have a positive and negative influence on IPM adoption and dis-adoption respectively. Farm income, measured in this study as the proportion of income generated from the farm out of the total annual household income, was also an important determinant of IPM adoption/dis-adoption, whose direction is indeterminate. Proxies for market and institutional information access considered in this study included access to fruit IPM training, extension services, and the input market. IPM training is expected to enhance farmers' knowledge of the benefits of the technology and therefore likely to positively influence IPM adoption and the opposite for dis-adoption.

Measured in minutes a mango farmer takes to walk to the nearest mango input market, shorter distances to the input market are expected to increase the probability of adoption as farmers can easily access the technologies. Access to extension services remains an important pathway to agricultural technology adoption. Measured in this study as a dummy variable if a farmer was visited by an extension officer 12 months before the survey, extension contact was hypothesized to have a positive influence on the adoption of IPM and, a contrasting direction on IPM dis-adoption.

Mango group membership, a dummy variable equal to one if a farmer belonged to a mango production and marketing group and zero otherwise, was used to test the effect of social capital and networks on IPM adoption/dis-adoption. Social capital and networks are important channels for information access in rural areas where markets are imperfect. They also enable farmers to access inputs and overcome marketing and credit challenges and are therefore expected to positively influence IPM adoption.

Technology attributes may positively or negatively influence a farmer's decision to adopt a technology. In this study, the unavailability of IPM, the perceived cost and quality of the most commercialized fruit fly IPM component (that is MAT) were controlled for, and all the variables measured as dummy. While the cost of the technology and unavailability are likely to inhibit farmers from the technology, the quality is likely to induce them to take it up, while a contrasting effect is expected for the dis-adoption decisions.

The Correlated Random Effects Probit Model was implemented by first generating the means for all the continuous explanatory variables such as age, household size, education of the household head, and distance to the input market, and then were included as additional covariates. The model was then fitted using the xtprobit command in STATA. In addition, the Random Effects Probit Model was also run to test for the robustness of the different determinants of adoption.

Estimation of the Discrete-time Proportional Hazard Model involved the creation of three new additional covariates including an interval identification variable, a period-specific censoring indicator, and the definition of variables as a function of time (Jenkins, 1998). The interval identification variable captured the duration of IPM adoption, that is, years from initial use to the survey (the year 2022). The period-specific variable was constructed to capture whether a mango farmer had left the IPM adoption state and entered the dis-adoption state. The model was then fitted using the pgmhaz command in STATA (Jenkins, 1998).

3.2.3 Data sources and sampling procedure

The data for the current study were obtained from mango farmers in the Runyenjes and Manyatta sub-counties of Embu County, Kenya. The county (Figure 3.1) was purposively selected by the

African Fruit Fly Program of *icipe* as a benchmark project site since it is one of the leading mango-producing counties in Kenya.

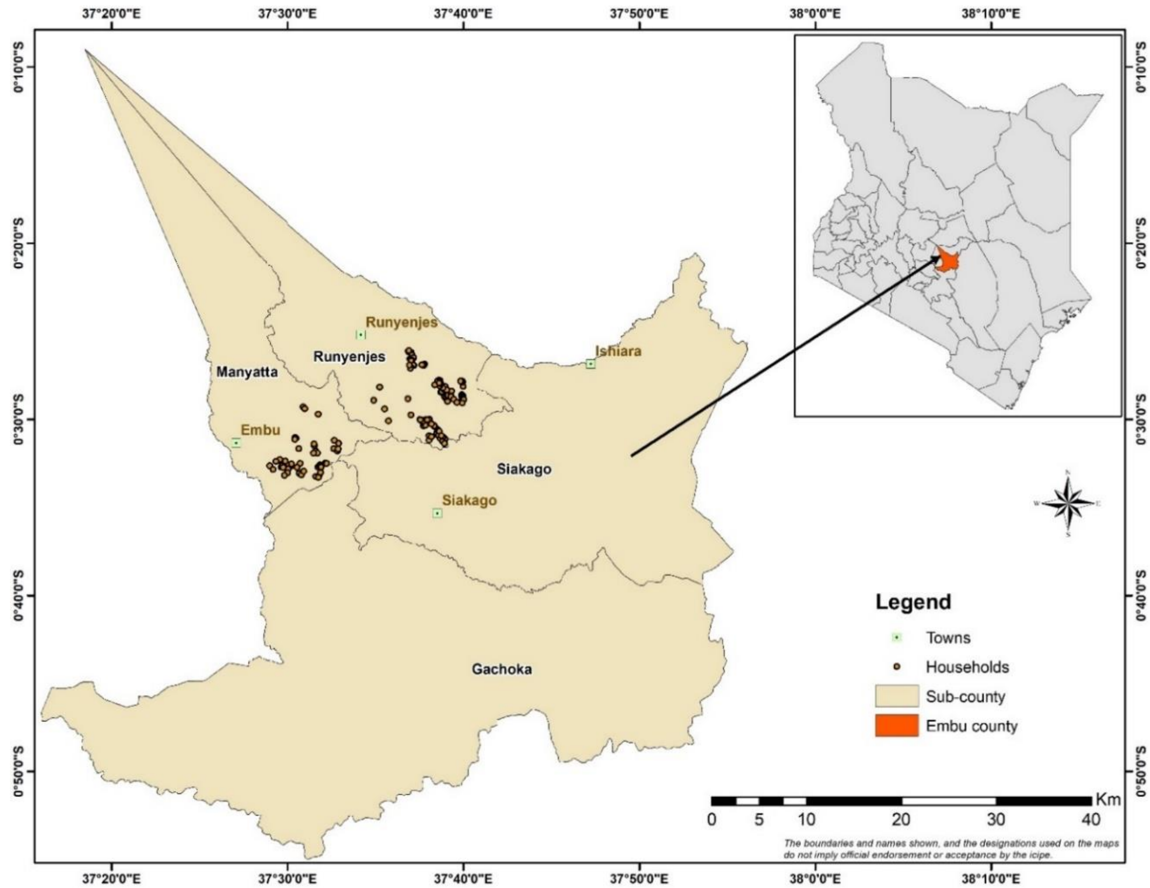

Figure 3.1:Map of the study area
Source: Wangithi et al., 2021

The data were collected in two phases; a baseline survey conducted in 2019 by Wangithi *et al*. (2021) and a follow-up survey conducted in 2022. The baseline survey used a cluster sampling technique to select 165 mango farmers in Embu County (Wangithi *et al.*, 2021). In the first stage, Runyenjes and Manayatta sub-counties were purposively selected since they lead mango production in the county. The sampling frame was a list of mango-growing households generated by sub-county agricultural officers. In the second stage, a simple random sampling technique was used to select 165 households from the two sub-counties following Taherdoost (2017). The follow-up survey targeted the same households interviewed during the baseline survey but only 149 households were accessed (approximately 11 percent attrition) due to relocation from the county. The current study used a balanced panel dataset of 149 households. More detailed descriptions of the study area, target population, sampling frame, and sample size are provided by Wangithi *et al*. (2021).

The baseline and follow-up datasets were collected using semi-structured questionnaires programmed in the Census and Survey Program System (CSPro) and collected through face-to-face interviews by trained enumerators. Data were analyzed using STATA 16.

3.3 Results

3.3.1 Descriptive Analysis

i) Farm, farmer, and IPM technology characteristics of mango growers in Kenya

Different classifications of farmers by IPM adoption were achieved by first asking the respondents whether they were using or had used the male annihilation technique (MAT) in the last mango production season. The classification generated three different adoption categories – adopters or dis-adopters of IPM; seasonal or continuous users of IPM; and, partial or whole farm users of IPM.

Adopters and dis-adopters were further divided into three different sub-categories; farmers who were using the male annihilation technique (MAT) at the time or had used in the previous mango production season were classified as *IPM adopters*; farmers who had never used MAT were classified as *IPM non-adopters*, while farmers who had used MAT earlier but had discontinued the use were classified as *IPM dis-adopters*. Based on this classification, 59 percent of the respondents were IPM adopters, 24 percent were non-adopters, and 17 percent were dis-adopters.

Table 3.2 presents a comparison of their farm, farmer, and IPM technology attributes. A statistical F test was conducted to test for differences in the variables across the different farmer categories.

Table 3.2: Comparison of farm, farmer, and fruit fly IPM technology attributes of mango-growing households across different adoption profiles in Embu County Kenya

Explanatory Variables	Mean				
	Pooled	IPM adopters	IPM non-adopters	IPM dis-adopters	F-Test
	n = 298	n = 176	n = 72	n = 50	
Household demographic characteristics					
Gender of household head (1=Male, 0=Female)	0.74	0.78	0.62	0.74	3.67**
Size of household(count)	3.57	3.66	3.43	3.48	0.49
Education of household head (years of schooling)	9.32	9.81	8.33	9.00	3.75**
Age of household head (years)	63.44	63.99	60.36	65.98	3.83**
Resources					
Proportion of annual farm income (percentage)	65.38	68.31	60.94	61.44	2.39
Farm size (acres)	4.13	4.62	3.21	3.73	2.61**
Market and institutional information access					
IPM training (1=Yes)	0.49	0.65	0.26	0.28	24.40***
Distance to input market (minutes taken when walking)	34.46	36.32	29.51	35.06	1.71
Contact extension officer(1=Yes)	0.43	0.55	0.27	0.26	12.40***
Access to credit services (1=Yes)	0.10	0.13	0.8	0.4	2.18
Social capital					
Mango group membership(1=Yes)	0.10	0.16	0.01	0.02	8.94***
Fruit fly IPM attributes					
Unavailability of IPM technology	0.45	0.48	0.51	0.56	9.01***
Cost of IPM technology	0.57	0.56	0.55	0.58	3.76**
Quality of IPM technology	0.41	0.44	0.4	0.38	6.70***

Note: F-Test for the three adoption profiles
Source: Survey data (2019 and 2022); **p < 0.05, ***p < 0.01

The results (Table 3.2) show that about a third of the fruit fly IPM non-adopting households were headed by females. The education of the household head was statistically different across the adoption profiles. Fruit fly IPM adopters had relatively higher education (10 years) compared to both the non-adopters (8 years) and dis-adopters (9 years). The average age of the household heads across the three different groups was significantly different. The average age of heads of fruit fly IPM dis-adopters (66 years) was relatively higher compared to both the adopters (64) and non-adopters (60) of the technology. Fruit fly IPM adopters had relatively bigger farm sizes (4.62 acres), compared to non-adopters (3.21 acres) and dis-adopters (3.73 acres). Further results indicated that a bigger proportion of fruit fly IPM adopters (65 percent) received training on IPM, compared to non-adopters (26 percent) and dis-adopters (28 percent). The majority of the dis-adopters perceived the availability (56 percent) and cost of fruit fly IPM (58 percent) to be constraints that hinder adoption and continuous use of the technology.

Figure 3.2 presents the additional reasons reported by the fruit fly IPM dis-adopting households. The major reason reported by 41 percent of the households was lack of money to buy IPM inputs.

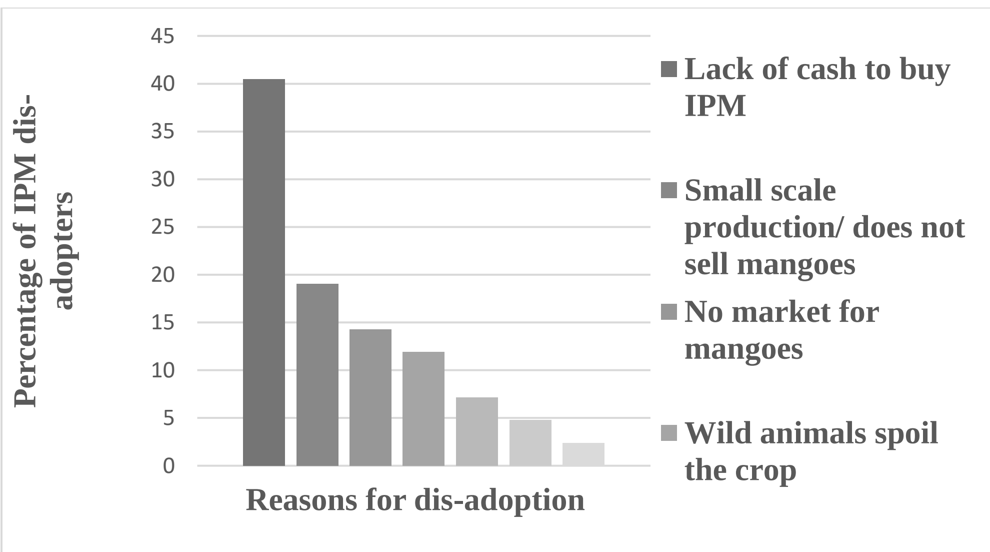

Figure 3.2: Reasons for Fruit Fly IPM Dis-adoption in Embu Kenya
Source: Survey data

These results are consistent with those of Wangithi *et al*. (2021) who found unavailability of IPM inputs in the market to be the main driver of dis-adoption.

ii) Seasonal use of fruit fly IPM

The second classification of IPM users was IPM use by season where, adopters were categorized as either seasonal users or continuous users. Comparison of seasonal and continuous users show that 71 percent of the IPM adopters were continuous users while 29 percent were seasonal users. The main constraint for the seasonal use of the IPM users was limited awareness or knowledge on the replacement of the lures, reported by 52 percent of the seasonal IPM users (Figure 3.3). Mango farmers also cited lack of cash to buy and maintain IPM, and the unavailability of IPM to be the second and third reasons respectively leading to the seasonal use of the technology.

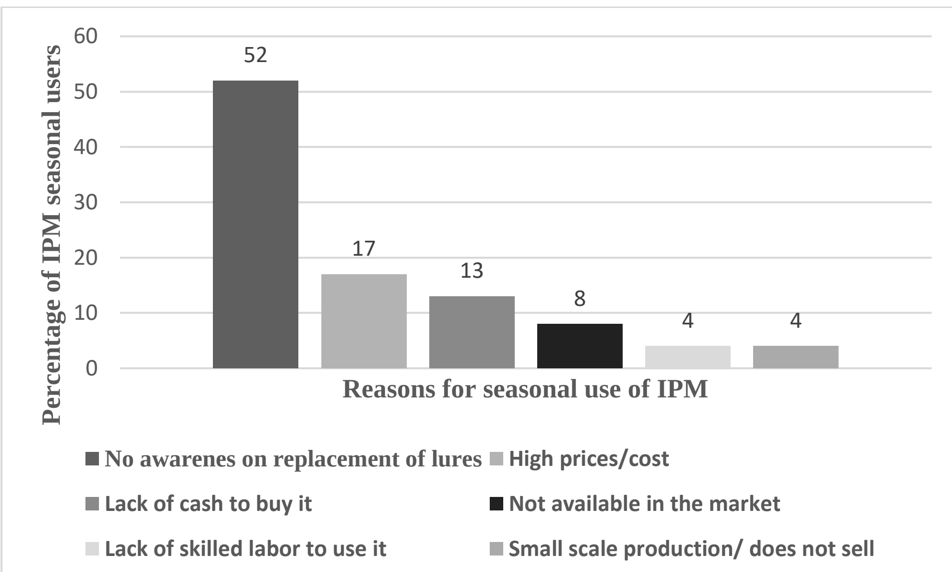

Figure 3.3 Reasons for Seasonal use of Fruit-fly IPM in Embu Kenya
Source: Survey data

iii) IPM use by the scale of application in the mango orchards

Even when the benefits of technology have been proven, the adoption of most introduced agricultural technologies is often partial, possibly to reduce the uncertainty in performance associated with innovations. 60 percent of the IPM adopters were whole-farm IPM users, while 40% were partial-farm IPM users. Lack of money to buy and service fruit fly traps was cited as the main constraint leading to partial-farm use of the technology (Figure3.4). Other constraints cited were the small-scale nature of production, lack of a ready market for their mangoes, crop destruction by wild animals, and lack of technical support in handling the technology. The perceived non-effectiveness of the IPM reported by a few respondents could be attributed to the incorrect timing of the replacement of the traps, suggesting the need for further training and technical support for enhanced adoption of the technology.

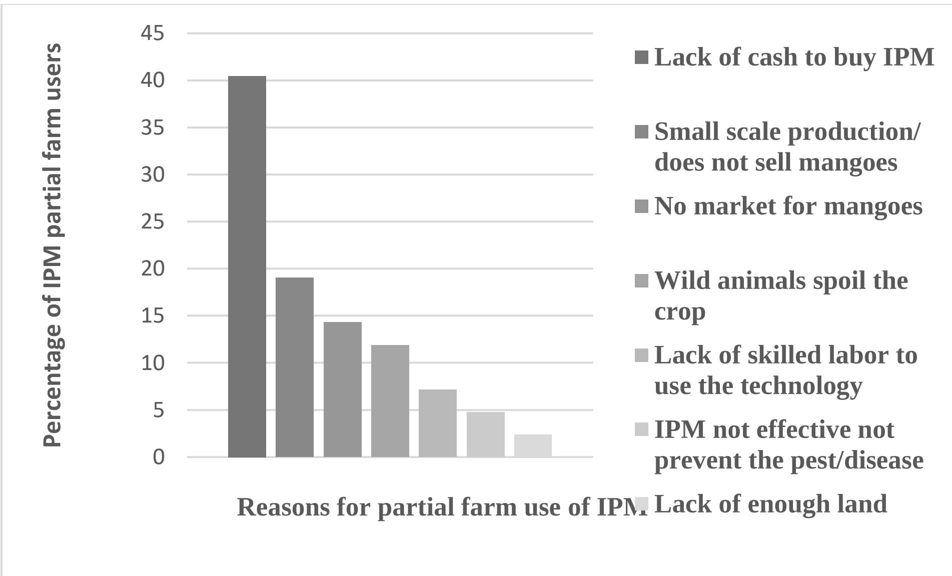

Figure 3.4: Reasons for Partial-farm use of Fruit-fly IPM in Embu Kenya
Source: Survey data

3.3.2 Empirical Results

The empirical analysis is based on adoption and dis-adoption of fruit fly IPM grouping because adequate data was not for the other groups.

i) Determinants of the adoption of fruit fly IPM

Table3.3 presents the maximum likelihood effects (MLE) of the factors influencing the adoption of IPM practices in controlling fruit fly infestation among mango growers in Embu County.

Table 3.3: Factors influencing the adoption of fruit fly IPM among mango farmers in Embu Kenya

IPM Adoption	Correlated Random Effects Probit	Random Effects Probit
Gender of household head	0.16***	0.12**
	(0.06)	(0.06)
Size of household (count)	0.01	0.01
	(.03)	(0.02)
Education of household head	0.05	0.01
	(0.01)	(0.01)
Age of household head (years)	-0.06***	-0.01*
	(0.01)	(0.02)
Farm size (acres)	0.01	0.04
	(0.01)	(0.06)
Proportion of annual farm income	0.00	0.00
	(.01)	(0.01)
IPM training (1=Yes)	0.27***	0.29***
	(0.56)	(0.06)
Distance to input market in walking minutes	0.08	0.08**
	(0.03)	(0.03)
Contact extension officer (1 = Yes)	0.13**	0.11**
	(0.05)	(0.06)
Mango group membership(1=Yes)	0.22**	0.20**
	(0.09)	(0.09)
Access to credit services (1 = Yes)	0.04	0.01
	(0.84)	(0.85)
Unavailability of IPM technology	-0.19***	-0.23***
	(0.05)	(0.06)
Cost of IPM technology	0.11**	0.11**
	(0.05)	(0.06)
Quality of IPM technology	0.07	-0.05
	(0.05)	(0.54)
Overall R^2	0.35	0.30
Number of observations	298	298
$\chi2$	142.17	111.56
Prob > $\chi2$	0.00	0.04

Significance at ***p < 0.01, **p < 0.05, *p < 0.1
Source: Survey data

The results show that age and the unavailability of IPM have statistically significant negative effects on the adoption of the technology while, gender, IPM training, access to extension, mango group membership and quality of IPM have positive and statistically significant influence on adoption.

ii) Determinants of fruit fly IPM dis-adoption among mango growers in Embu, Kenya

Table3.4 presents the results for the dis-adoption decisions. The risk of exit from adoption to dis-adoption is shown by the hazard rate, which shows the number of mango farmers found in the adoption state at the time of observation (Alem *et al*., 2014).

Table 3.4: Determinants of fruit-fly IPM dis-adoption among mango growers in Embu Kenya

IPM Dis-adoption	Coefficient	Standard Error
Gender of household head (1=Male, 0=Female)	0.89*	0.47
Size of household(count)	-0.01	0.11
Education of household head (years of schooling)	0.18 ***	0.06
Age of household head (years)	0.04**	0.02
Farm size (acres)	0.20***	0.01
Proportion of annual farm income (percentage)	0.01	0.05
IPM training (1=Yes)	0.77	0.31
Distance to input market (minutes taken when walking)	-0.13	0.30
Contact extension officer(1=Yes)	0.01	0.56
Mango group membership(1=Yes)	-0.91	0.98
Access to credit services (1=Yes)	-0.52	0.64
Unavailability of IPM technology	-0.52	0.33
Cost of IPM technology	0.02	0.31
Quality of IPM technology	0.71**	0.33
Constant	-6.01 ***	1.41
Log-likelihood	-81.12	
Number of observations	298	
$\chi 2$	155.40	
Prob > $\chi 2$	0.00	

Standard errors in parenthesis; significance at ***<0.01, **<0.05, *<0.1
Source: Survey data

The gender, education, and age of the household head, the farm size, and, the perceived quality of MAT have positive and statistically significant effects on the hazard rate.

3.4 Discussions

3.4.1 Adoption of fruit-fly IPM by scale and seasonality of use

The partial fruit fly IPM adopters only applied the technology on a few of their mango sub-plots or sections of the orchard, and limited resources to buy and service the traps were cited as the main challenge. Other reasons included a lack of a ready market to sell high-quality fruits to compensate for their efforts to implement the technology in other sections of their orchards. Lack of technical support contributing to lack of knowledge was also highlighted as one of the reasons contributing to partial adoption of the technology. As noted by Wangithi *et al*. (2021), the partial adopters were not using the recommended rates for the replacement of the lures and hence reported the ineffectiveness of the technology in controlling the fruit fly pest.

Seasonal use of the fruit fly IPM reported lack of knowledge on the replacement of lures as the main constraint followed by unavailability of IPM inputs in the market and their high prices .These findings corroborate those of Wangithi *et al*. (2021). In addition, lack of technical skills in using IPM products was also a contributing factor to the seasonal use of the technology. These constraints are similar to those reported by previous studies on the adoption of agricultural technologies (Quisumbing and Pandolfelli, 2010; Feyisa, 2020).

3.4.2 Determinants of fruit fly IPM adoption among mango growers in Embu Kenya

Age of the household head negatively influenced the adoption of the fruit fly IPM, suggesting a lack of receptivity among older farmers toward newly introduced technologies (Arellanes and Lee, 2003). Older farmers who have spent more time growing mango may be reluctant to take the risk of adopting new unfamiliar technologies for the management of mango fruit flies as found by Kafle (2010) who associated the negative effect of age on adoption with the risk averseness and unwillingness of older farmers to accept change in the production techniques that they have previously used.

Contact with agricultural extension service providers, a proxy for access to information, was positively related to the adoption of IPM.As reported by Kafle(2010) regular contact with extension agents enhances awareness of new technologies and the skills needed to use them. Fisher *et al*. (2015) also reported that farmers who received information on modern technologies were more likely to adopt them as compared to those who did not. IPM training seeks to increase awareness and impart skills needed in the adoption of IPM technology. Parsa *et al*. (2014) noted that insufficient training and technical support are the major obstacles to IPM adoption in developing countries. Quazi and Talukder (2011) and Biniam *et al*. (2019) noted that training and extension contact are important predictors of perception and acceptance behavior of individuals toward new technologies.

Social capital through membership in the mango group positively influences the adoption of IPM technology. Manda *et al*. (2020) reported that farmer groups provide avenues that enhance easy training and dissemination of new technologies as well as, access to credit services that farmers use to purchase new technologies. Our findings are in line with the findings of Onyeneke(2017) who reported that group membership facilitates easy access to agricultural production inputs thereby, enhancing adoption. In addition, group membership aids farmers to access credit services, extension information regarding the crop, and access to output markets (Biniam *et al*., 2019).

Technology characteristics including awareness, accessibility, application, benefits, and operating costs determine the sustainable adoption of a technology (Fadeyi *et al.*, 2022). The perceived unavailability of IPM technology negatively influences the adoption of the technology. This is plausible since farmers adopt technologies that they can easily access. These results support the findings of Andrade *et al*. (2019) who reported that technologies need to be available for enhanced adoption by smallholders. The results of the perceived operational costs of the IPM technology corroborate the Asiedu-Ayeh *et al*. (2022) finding which reported that the perceived cost of new technology is not a hindrance to its adoption as farmers consider whether the intended benefits outweigh the associated costs when making the adoption decision.

3.4.3 Determinants of fruit IPM dis-adoption among mango growers in Embu, Kenya

Larger farm sizes were found to positively influence continued use of IPM positively and to discourage the dis-adoption of the technology. The farm size is a proxy of household resources and larger farm sizes are attributed to the adoption of modern technologies (Kehinde, 2017). Years of formal education has a positive impact on the hazard of exit from IPM adoption. The educational level of the farmers is often associated with the continued use of agricultural technologies as it increases the ability to obtain, process, understand, and interpret agricultural information acquired from different sources (Kehinde, 2017). The gender of the household head had a positive impact on the hazard of exit from the adoption state of IPM, suggesting that women are more likely to dis-adopt IPM compared to men. Men were the majority among plot managers and had greater access to resources as compared to women, therefore, male-headed households are likely to adopt and continue using technologies as compared to female-headed households (Wangithi *et al*.,2021).

For the technology characteristics, the perceived quality of IPM was positively associated with the hazard of exit from adoption. The perceived quality of IPM enhances the adoption decisions and sustained use of the technology by mango farmers. Most farmers do not perceive the quality of IPM as a constraint to continued use of the technology. This finding is consistent with that of Fadeyi *et al*. (2022) who reported that farmers' awareness of technology's quality, use, and benefits enhance its adoption.

3.5 Conclusions and Policy Recommendations

This study evaluated the determinants of the adoption and dis-adoption of fruit fly IPM. Descriptive results have shown that 59 percent of the survey respondents were IPM adopters, 24 percent were non-adopters and 17 percent were dis-adopters. Additionally, 40 percent of the adopters were partial farm users and 29 percent were seasonal users of IPM technology. Farmers who had discontinued the use of IPM technology cited the unavailability of the technology (32 percent) as the main reason for dis-adoption. Seasonal users of the technology similarly reported the unavailability of IPM in the market to be the main reason for this tendency while, partial-farm use of the technology was attributed to a lack of cash to buy and maintain the technology. Therefore, IPM technology should be made easily accessible to promote sustained adoption of the technology and to discourage dis-adoption, seasonal and partial use of the technology.

The empirical results of the IPM adoption model show that the gender of the household head, contact with an extension officer, IPM training, mango group membership, and the perceived cost of IPM positively influenced the adoption of IPM practices in the suppression of mango fruit fly infestation. Furthermore, the age of the household head and the unavailability of IPM products had a negative influence on the adoption of the technology. On the hazard of exiting adoption to dis-adoption of the technology, education of the household head, age of the household head, farm size, and the perceived quality of IPM positively influenced sustained adoption of IPM. This study therefore, recommends building the capacity of mango farmers through training and access to extension services to enhance the adoption of this technology and discourage dis-adoption. This can be achieved through, research organizations intensifying information dissemination through extension officers and farmer groups on the importance of the technology. In addition, the IPM products should be made easily accessible to farmers to improve availability and sustained adoption of the technology.

CHAPTER FOUR: IMPACT OF ADOPTION OF IMPROVED INTEGRATED PEST MANAGEMENT PRACTICES IN THE SUPPRESSION OF MANGO FRUIT FLY INFESTATION IN EMBU COUNTY, KENYA

Abstract

This study utilized a two-wave panel data to estimate the impact of a bundle of Integrated Pest Management (IPM) practices on three outcome variables (net income, expenditure on pesticides, and post-harvest losses) arising from the suppression of fruit fly infestation among mango farmers in Embu County, Kenya. A difference-in-difference model was fitted on a sample of 149 mango farmers drawn using a cluster sampling method to estimate the impacts of IPM while a fixed effects model was used to test for the model's robustness. The impacts were differentiated by three treatments including the use of male annihilation technique (MAT) only, auto-dissemination technique (ADT) only, and using both MAT and ADT, while the conventional fruit fly management method (use of chemical pesticides) was used as the control group. The results show increased mango net income among the treated groups and reduced expenditure on pesticides and post-harvest losses among the same group compared to the control. Farmers who received MAT+ADT intervention reported the highest increase in mango net income and, a reduction in the expenditure on pesticides and postharvest losses due to fruit fly infestations. Further results show a negative effect of group membership on the proportion of post-harvest losses, and a positive influence of access to extension on mango farmers' net income. The study recommends the integration of the auto-dissemination technique into the existing conventional fruit fly IPM components to enhance the suppression of invasive pests. In addition, development initiatives that promote information dissemination through innovative agricultural extension approaches and mango production and marketing groups are recommended.

4.1 Introduction

Fruit production contributes substantially to employment creation, income generation, and food and nutritional security globally, and in Sub-Saharan Africa (FPEAK, 2020; FAO and CIRAD, 2021). In Kenya, mango is the second most important fruit after bananas in terms of the value of production (HCD, 2017; Wangithi *et al*., 2021). On the average, the gross value of mango production in Kenya is estimated at USD 84.4 million per year (FAO, 2022). The mango value chain has the potential to provide an additional 3.2 million employment opportunities in Kenya (CABE, 2022). Over 50 percent of Kenya's mango exports are destined to the United Arabs Emirates while France, Germany, the United Kingdom, Saudi Arabia, and other Middle East countries share the balance (KALRO, 2019; Tridge, 2019; Bien and Soehn, 2022).

Despite the economic importance of mango in Kenya, production, and marketing of the fruit are constrained by several factors (HCD, 2017). Pest and diseases infestation is ranked as the most important production constraint due to the resulting economic losses arising from limited access to export markets owing to sanitary and phytosanitary regulations (HCD, 2017; SNV, 2018; UNIDO, 2020). Fruit fly infestation has been reported to be the dominant invasive pest in mango production due to the magnitude of losses that they cause (Ekesi *et al*., 2016). In Kenya, during the 2014 -2021 period, the quarantine measures for fruit flies reduced annual net mango revenue by over USD110 million (Agrilinks, 2022). Mango losses attributed to fruit fly infestation account for more than 40 percent of all mango losses (Agrilinks, 2022).

In an attempt to reduce mango fruit fly infestation, farmers often use broad-spectrum chemical pesticides (Mwungu *et al*., 2020). However, the conventional use of chemical pesticides to control fruit flies is unsustainable since they are not only expensive, especially for smallholder farmers but also pose negative risks to the environment and human health (Mwungu *et al*., 2020). Mango farmers have also used indigenous methods such as herbs and plant-based solutions which they perceive to be less costly, but often less effective in the control of invasive pests *(*Wangithi *et al*., 2021). Since 2012, the International Center of Insect Physiology and Ecology (*icipe*) and its partners have established and promoted fruit fly Integrated Pest Management (IPM) as a more effective and sustainable approach to the suppression of fruit flies.

The IPM package combines different strategies to suppress pests and enhance its effectiveness (Ekesi *et al*., 2016; Midingoyi *et al*., 2019; Mwungu *et al*., 2020). The fruit fly IPM promoted by *icipe* and partners aims at improving mango yield, farmers' net income, reducing costs of mango production, while preserving the environment (Ekesi *et al*., 2016; Muriithi *et al*., 2016; Midingoyi *et al*., 2019). The adoption of the IPM package has been reported to produce desirable results on different outcome variables in mango production including yield, quantities failings to meet export requirements, net income, and food security (Kibira *et al*., 2015; Muriithi *et al*., 2016; Muriithi and Gichungi, 2018; Midingoyi *et al*., 2019; Githiomi *et al*., 2019; Mwungu *et al*., 2020; Nyang'au *et al*., 2020).

The conventional fruit fly IPM released by *icipe* and partners has five components (that is, spot spray of food bait, male annihilation technique, Metarhizium anisopliae-based bio-pesticide application, releases of the parasitoid, and use of orchard sanitation). Recently, *icipe* and her partners have developed and rolled out an auto-dissemination technique to be integrated with the existing conventional components to improve the effectiveness of the IPM technology package.

Auto-dissemination is an ecologically based strategy where insects are used as smart and reliable conveyors of bio-pesticides. The technique involves attracting wild fruit fly males to stations baited with male-specific lures and fungal spores (Pope *et al*., 2018). Through mating and other social behavior, they subsequently transfer the fungal spores to target habitats and counterparts (Pope *et al.*, 2018).

Despite the reported economic benefits of the mango fruit fly IPM technology package, the impacts of the integration with an auto-dissemination technique are not documented. Although there are some reports on the use of the auto-dissemination technique in the control of diamond black moth, tick vectors, and malaria, the available literature on technology adoption barely covers the promotion of the technique among farmers (Vickers *et al*., 2004; Caputo *et al*., 2012; Lwetoijera *et al*., 2014; Weeks *et al*., 2020). Furthermore, the studies on the auto-dissemination technique reported were based on laboratory and mini field experiments.

Most past studies reported the economic benefits of the mango fruit fly IPM package with no special emphasis on the IPM technology-specific factors which would require estimation of conditional effects of the technology. In an attempt to bridge this gap in knowledge, this study evaluates the impact of integrating the auto-dissemination technique with the conventional mango fruit fly IPM technology package in managing fruit fly infestation. The study tests a key hypothesis that "integrating the auto-dissemination technique with the conventional mango fruit fly IPM technology package has no impact on mango net income, expenditure on pesticides and on the proportion of post-harvest losses".

The study contributes to the literature in three ways; First, it includes IPM technology-specific factors when measuring the conditional treatment effects of the technology. Secondly, it reports the impacts of the proposed integration of the conventional mango fruit fly IPM technology package with an auto-dissemination technique in the suppression of mango fruit flies. Lastly, it disaggregates the respondents into three different treated groups and a control group, and, measures the impact of use of the IPM technology package on three different outcome variables.

A difference-in-difference model is fitted on a two-period dataset to measure the impact on the four outcome variables including mango net income, expenditure on synthetic pesticides, and the proportion of mango postharvest losses due to fruit fly infestation. The male annihilation technique (MAT) was used as a proxy for the mango fruit fly IPM technology adoption since it is the most common and commercialized component and its use alone produces significant results (Muriithi *et al*., 2016; Wangithi *et al*., 2021). The impact was measured on three categories of mango farmers; farmers treated with the male annihilation technique (MAT), farmers treated with auto-dissemination technique (ADT), farmers treated with the combination of MAT+ADT, and the control group that included farmers who were using conventional methods such as synthetic pesticides, indigenous methods, and their innovations. The results show that regardless of the treatment, farmers who were treated reported increased mango net income, and reduced expenditure on synthetic pesticides and postharvest losses from fruit fly infestation.

4.2 Study Methods

4.2.1 Theoretical framework

The decision to adopt an IPM technology in this study was modelled using the random utility framework (Cascetta, 2009). Following Greene (2002), the utility function for the adoption of mango fruit fly IPM technology was specified as follows:

$$U^{a} = X' \beta_{ipm} + \varepsilon_{ipm} \tag{4.1}$$

$$U^{n} = X' \beta_{ipm} + \varepsilon_{ipm} \tag{4.2}$$

where; U^{a} is the utility derived from adopting the mango fruit fly IPM technology; U^{n} is the utility derived by the farmers from not adopting the IPM technology. The Xs are the explanatory variables, β's are the parameters to be estimated and ε is the random error term. If a farmer adopts the technology IPM (that is U^{a}>U^{n}) then the observe measure of adoption equals one (1) while, if a farmer does not adopt the IPM technology then the observed measure of adoption equals to zero (0).

This study assumed that adoption of new technologies such as IPM can help to increase mango net income, reduce expenditure on pesticides and the proportion of mango post-harvest losses (Kassie *et al*., 2011). Assuming that the outcome variables of interest (mango net income, expenditure on pesticides and proportion of mango post-harvest losses) is a linear function of the improved IPM technology and a vector of other explanatory variables, the following equation yields;

$$Y_{ipm} = X \phi_{ipm} + \delta S_{ipm} + \mu_{ipm} \tag{4.3}$$

Where Y_{ipm} represents the outcome variables of interest, X are the explanatory variables, S the IPM intervention, ϕ and δ are the parameters to be estimated, μ is the random error term.

The impact of adoption of the improved IPM technology on the outcome variables is measured by the estimation of parameter δ in equation 4.3. However, to accurately measure the impact of adoption of improved IPM on the outcome variables, farmers need to be assigned randomly to adoption and non-adoption groups (Faltermeier and Abdulai, 2009; Khonje *et al*., 2015). In the absence of the random assignment, farmers would self-select into groups making the estimated parameter δ to biased (Maddala, 1983). Econometric methods that have been suggested to address the problem of self-selection include propensity score matching (PSM), the difference in difference, endogenous switching regression model, and instrumental variables (ADB, 2006; Greene, 2008). Given that this study had two groups of farmers (the treated and control) and further that the data were collected before and after the treatment(two wave panel), then the difference in difference (DiD) method was found to be appropriate in evaluating the impact of adoption of the improved IPM technology on the outcome variables (ADB, 2006). The baseline data were collected before the treatment in 2019 and the follow up after the treatment in 2022. In all cases, the control group was maintained.

4.2.2 Empirical Model

To measure the impact of the integration of the conventional IPM technology package with the auto-dissemination technique, this study utilized a two wave panel data and estimated a DiD model. The explanatory variables included the three treatments (ADT, MAT, and MAT+ADT), household characteristics and other contextual variables while the dependent variables comprised the three outcome variables (that is mango net income, expenditure on pesticides, and the proportion of postharvest losses due to fruit flies). The two interventions MAT and ADT were combined to form three treatments; treatment 1: use of male annihilation technique (MAT), treatment 2: use of auto-dissemination technique (ADT), and treatment 3: MAT+ADT. The DiD is obtained by comparing the change in the outcome parameters for the treated and the control groups before and after the intervention (Palmer-Jones, 2010). The DiD model was specified as follows;

$$y_i = \alpha + \theta t + \beta_1 MAT + \tau_1\, t * MAT + \beta_2 ADT + \tau_2\, t * ADT + \beta_3 ADTMAT + \tau_3\, t * ADTMAT + \gamma X_i + \varepsilon_i \qquad (4.4)$$

Where y is the outcome variable of interest (mango net income, expenditure on pesticides, and proportion of postharvest losses from fruit fly infestation); θ is the time coefficient which shows changes over time that are independent of the intervention. To account for the different treatments, the dummy variables MAT, ADT and MAT+ADT ($\tau_1 \ldots\ldots \tau_3$) are used to represent the coefficients of interaction between time and the dummy variables accounting for the different treatments that show the effect of each treatment on the outcome variables. ($\beta_1 \ldots\ldots \beta_3$) are the coefficients of the dummy variables accounting for the different treatments that show the initial difference in the outcome variable between the treatment and the control group are represented by $\beta_1 \ldots \beta_3$. Other exogenous variables of interest included the perceived quality of IPM and membership to a mango production and marketing group that may affect the dependent variable are represented by X.

The fixed effects estimator was implemented as a robust check since DiD does not control for the unobserved time-invariant heterogeneity. Given that the fixed effects estimator allows for correlation between the unobserved heterogeneity and any exogenous variable in any time period, the explanatory variables that are constant over time such as gender of the household head are excluded during the transformation (Wooldridge, 2015). Further, the dummy variables for the treatments were dropped since they are also time-invariant (Muriithi *et al*., 2016). The fixed effects model for this study was specified following (Muriithi *et al.*, 2016) as;

$$y_i = \theta t_{it} + \tau_1\, t * MAT + \tau_2\, t * ADT + \tau_3\, t * ADTMAT + \gamma X_i + \eta_i + \varepsilon_i \qquad (4.5)$$

Where η is the unobserved individual heterogeneity which is time-constant and may be correlated with both the treatment and the unobserved characteristics.

4.2.3 Definition and measurement of variables

The choice for the outcome and explanatory variables shown in Table 4.1 was guided by literature on agricultural technologies adoption including fruit fly IPM (Korir *et al*., 2015; Muriithi and Gichungi, 2018; Muriithi *et al*., 2020; Mwungu *et al*., 2020; Nyang'au *et al*., 2020; Muriithi *et al*., 2021; Wangithi *et al*., 2021).

The mango net income was computed as a gross margin (total revenue from mango output less the variable cost of production) in Kenya Shillings per acre (Kshs/acre). The proportion of postharvest losses was estimated as the output of damaged mangoes due to fruit fly infestation as a share of the total output of mangoes per farm (percentage). The total mango pesticide expenditure was evaluated as the total cost of pesticides per unit of mango production (Kshs/acre).

Gender was measured as a dummy variable where a male-headed household was assigned one and a female-headed household a zero. Education was measured as the total number of years of formal education. The age of the household head was measured as the total number of years of the household head. The extension was a dummy variable whereby farmers who were visited by an extension in the last year before the survey were assigned one.

Table 4.1: Description of variables used in the Difference in Difference Model

Variable	Variable Definition	Hypothesized signs
Net Mango income	Gross margin (total revenue from mango output less the variable cost of production) in Kenya Shillings per acre (Kshs/acre)	
Pesticide Expenditure	Total cost of pesticides per unit of mango production (Kshs/acre).	
Proportion of fruit fly postharvest losses	Output of damaged mangos due to fruit fly infestation as a share of the total output of mangoes per farm (percentage)	
Treatment Dummy	Fruit fly IPM treatment dummy for fruit fly IPM; 1= Treatment, 0= control	−/+
Time	The period when the survey was done; 0=baseline, 1=follow-up	−/+
Treatment*Time	IPM intervention; 1= after for a household with the intervention, 0= after/before for a household without an intervention	−/+
Gender	Gender of household head 1 = male 0 = Female	−/+
Education	Number of schooling years of the household head	−/+
Age	Age of the household head in years	−/+
Extension	If a farmer was visited by an extension officer in the last 12 months 1=yes, 0= No	−/+
Group membership	Membership in a mango production/marketing group 1 = Yes, 0 = No	−/+
Credit	Accessed agricultural credit services 1=yes, 0=No	−/+
Unavailability of IPM technology	Whether the unavailability of IPM is a constraint in the adoption 1=yes, 0=No	−/+
Labor of IPM technology	Whether labor requirement in the use and maintenance of IPM is a constraint in the adoption 1=yes, 0=No	−/+
Quality of IPM technology	Whether the quality of IPM is a constraint in the adoption 1=yes, 0=No	−/+

Group membership was a dummy variable that is, one to a farmer who belonged to a mango production and marketing group and zeroes otherwise. Credit was a dummy variable where farmers who accessed agricultural credit services were assigned one and zero otherwise. The unavailability of IPM was a dummy where farmers who perceived it as a constraint were assigned one. Labour of IPM was one for farmers who perceived labour requirements in the use and maintenance of IPM to be a constraint. The quality of IPM was also measured as a dummy variable where one was assigned to farmers who perceived IPM quality as a constraint to the adoption.

4.2.4 Data sources and sampling procedure

The data utilized in this study were collected from mango-growing households in Embu County. The County was chosen since it is one of the top mango-producing counties (HCD, 2017) and has been one of the sites where the African Fruit Fly Program is implemented by *icipe* since its inception in 2012. The data were collected from 165 farmers over two time periods, 2019 and 2022 referred to as “before treatment” and “after treatment “respectively. The “treatment” involved availing fruit fly IPM technologies to some farmers. Therefore, the sample of mango farmers consisted of the “treated group” and the “control group” selected from the farmers who did not access the technologies.

The baseline survey conducted by Wangithi *et al*., (2021) 2019 employed a cluster sampling technique to select 165 mango farmers in Embu County, Kenya. In the first stage, two Sub-counties (Runyenjes and Manayatta) were purposively selected. In the second stage, a simple random sampling technique was used to select 165 mango farmers spread across the two sub-counties following Taherdoost (2017) formula. The baseline survey was conducted in August 2019 following the October 2018-April 2019 Mango season and thereafter, the interventions were issued to the selected treated group in 2019.

The follow-up survey was conducted in April 2022 preceding the October 2021-April 2022 Mango season among the same households selected in the baseline survey. The follow-up survey managed to reach 149 households and, the attrition of 11 percent was attributed to attrition as some baseline farmers relocated to other Counties. A detailed description of the study area, target population, sampling frame, and the sample size is provided by Wangithi *et al*., (2021). The data were collected using a semi-structured questionnaire programmed in Census and Survey Program System (CSPro). The data were collected through face-to-face interviews with trained enumerators. Using the baseline (165 households) and the follow-up (149 households) datasets, a balanced panel data of 149 households was developed resulting in 298 observations. The data were analysed in STATA version 16.

4.3 Results and discussions

4.3.1 Descriptive results

The farm, farmer, and IPM technology-specific characteristics of mango framers in Embu County are presented in Table 4.2. A test of the difference of means across the treatment groups was conducted using the F-test. The farmers using the MAT+ADT IPM technology package had the highest education achievement of 10 years and the difference with the other groups was statistically significant at the 1 percent level. Education has been reported to enhance skills, uptake, and efficient utilization of information (Kibira *et al*., 2015). The findings are consistent with the results of Moli *et al*. (2021) who reported that technology adopters have more years of formal education as compared to non-adopters.

Table 4.2: Sociodemographic profiles of mango Farmers in Embu County, Kenya

Explanatory Variables	Male annihilation technique (MAT)	Auto-dissemination technique (ADT)	MAT+ADT	Control	F
Gender	0.77	0.75	0.76	0.69	0.64
Education	8.53	8.42	10.44	9.03	5.15***
Age	61.98	64.58	62.43	65.68	2.37*
Extension	0.45	0.63	0.64	0.25	10.41***
Group membership	0.09	0.19	0.10	0.08	1.11
Credit	8.04	14.29	22.22	7.61	2.27*
Unavailability of IPM technology	0.39	0.47	0.48	0.48	0.68
Labor of IPM technology	0.28	0.32	0.23	0.52	6.54***
Quality of IPM technology	0.33	0.40	0.46	0.57	2.41*

Source: Survey data
Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

The average age of the farmers in the control group was relatively higher (65 years) than the treated farmers (62 years for farmers treated with MAT+ADT, 61 years for farmers treated with MAT and 64 years for farmers who had adopted). Older farmers have been reported to be skeptical about new technologies and are likely to abandon their use (Teklewold *et al.*, 2013).

Sixty-four percent of the farmers using the MAT+ADT IPM package were visited by extension officers in the last one year and the difference in access to extension was statistically significant across the four groups. Further results show that 22 percent of farmers using MAT+ADT had access to agricultural credit as compared to 8 percent for farmers using MAT only, 14 percent for ADT adopters), and 7 percent for the control group. Most of the farmers in the control group perceived labor requirements in the use and maintenance of IPM (52 percent) and quality of IPM

(57 percent) as constraints to IPM adoption and the differences across the treatment groups were statistically significant at least at the 10 percent level.

Table 4.3 reports the differences in means of the three outcome variables across the three different treatments and the control groups. An F test with Bonferroni-adjusted significance was run to test for overall statistical differences in means across and between four groups.

Table 4.3: Farm returns of Mango farmers in Embu County Kenya

Outcome Variables	Male annihilation technique (MAT) n = 92	Auto-dissemination technique (ADT) n = 36	MAT+ADT n = 56	Control n = 112	Pooled n = 298	F
Net Mango income (Ksh/acre)	36721.90 (3988.83)	35913.34 (4798.12)	35213.96 (4353.82)	15193.64 (2252.87)	28064.98 (1886.63)	10.27***
Expenditure on pesticides (Ksh/acre)	4366.98 (665.43)	3229.18 (1145.22)	2731.23 (515.14)	5534.32 (1142.48)	4338.27 (507.29)	1.58
Proportion of fruit fly postharvest losses (Percent of total production)	24.34 (1.33)	28.30 (1.98)	21.81 (2.10)	38.47 (2.09)	30.09 (1.073)	15.08***

Standard errors in parenthesis; significance at ***< 0.01, **< 0.05, *< 0.1
Source: Survey data

The net mango income was highest for farmers treated with the MAT technique (Kshs 36,722/acre) (1US$ = Kshs 120) and lowest for the control group (Kshs 15,194/acre) and the differences across the four treatment groups were statistically significant. The control group had the highest expenditure on mango pesticides while the MAT+ADT treatment had the lowest pesticides expenditure though the differences across groups was statistically insignificant. As would be expected, the share of PHL from mango fruit fly infestation was highest in the control group (38 percent) and lowest among the MAT+ADT treatment (22 percent) and the statistical differences between groups were statistically significant at the 1 percent level.

4.3.2 Econometric results

Before implementing the DiD model, preliminary validity checks were conducted to test for multicollinearity and heteroskedasticity. Results from the variance inflation factor (VIF) and the tolerance test as well as, Pearson's partial correlation test show that there is no potential high correlation between a given explanatory variable and other explanatory variables included in the regression models. To test if the error variance was not changing over a range of measured values, Breusch-Pagan Test was conducted and the results of this test confirmed the presence of homoscedasticity.

The unconditional treatment effects of the fruit fly IPM packages were estimated without controlling for other exogenous variables (Appendix 2). The impacts of the different IPM treatments were evaluated with the assumption that users and non-users had no other differences apart from the fact that the users were treated with the IPM components while non-users were not treated. The coefficients of ADT*Time, and MAT+ADT*Time were statistically significant across all the outcome variables and had the expected signs. However, the coefficient for MAT*Time was statistically insignificant for expenditure on pesticides but significant for all the other two outcome variables.

Table 4.4 presents the results of the conditional treatment effects. To evaluate the conditional treatment effects of the fruit fly IPM strategies, the DiD was implemented with the farm, farmer characteristics, and, technology-specific characteristics controlled for. The outcome measures have been captured in the different columns starting with net mango income, expenditure on pesticides, and proportion of postharvest losses due to fruit flies.

Mango farmers who received MAT+ADT intervention reported the highest increase in net income from mango production (42,960 Kshs/acre). Farmers who were treated with ADT also reported an increase in net income of 26,552 Kshs/acre while, farmers treated with MAT reported an increase of 24,424 Ksh/acre. The adoption of different mango fruit fly IPM technology packages has been reported to increases farmers net income (Muriithi *et al*., 2016). The results are consistent with the findings of Ma and Abdulai (2018) who reported that the use of IPM technology practices has a positive and statistically significant impact on net apple returns. Other contextual variables that had statistically significant effects on mango net income included age, education, access to extension services, unavailability of IPM, and labor requirements in the use and maintenance of the IPM technology package.

An extra year of schooling increased mango framers net incomes by 1,196 Kshs/acre. Education is a proxy to human capital and hence, farmers with more years of formal education can easily understand the benefits of the new technology (Rahman, 2022). Older farmers reported a decline in mango net income of 438 Kshs/acre. The age of the household head is negatively correlated with the mango net income. As farmers grow older, they become risk averse and are likely not to adopt new technologies consequently, leading to a reduction in the mango net income (Kafle, 2010).

Table 4.4: DiD estimates of the effects of fruit fly IPM adoption on outcome variables among mango farmers in Embu, Kenya

	Net Mango Income (Ksh/acre)	Expenditure on Pesticides (Ksh/acre)	Proportion of Fruit fly Losses (Percent of total production)
Time	2344.93*	-302.71	-0.68
	(1268.69)	(395.27)	(0.73)
Auto-dissemination	10366.70	930.32	-1.29
technique (ADT)	(6868.45)	(2657.38)	(4.25)
ADT*Time	26552.02***	-6188.24**	-30.36***
	(9671.05)	(2010.12)	(5.22)
Male annihilation	3364.55	1333.36	3.24
technique (MAT)	(5559.92)	(1376.87)	(3.14)
MAT*Time	24424.78***	-3804.69	-30.26***
	(9034.54)	(2403.04)	(4.51)
MAT+ADT	-5598.30	1041.07	12.25***
	(4653.42)	(1287.34)	(3.78)
(MAT+ADT) *Time	42960.68***	-7226.51**	-27.18***
	(8824.21)	(3360.54)	(4.90)
Gender	2918.46	-635.30	-1.31
	(3866.70)	(1084.14)	(2.43)
Education	1196.87**	-183.90	-0.02
	(557.14)	(90.93)	(0.27)
Age	-438.45***	10.52	0.04
	(156.42)	(33.02)	(0.10)
Extension	4397.21***	-1244.27	-30.30***
	(3903.94)	(1075.43)	(2.01)
Group membership	5078.10	-7265.96	-31.23*
	(6940.80)	(4359.66)	(2.69)
Credit	3364.25	-3075.03**	-0.13
	(4866.54)	(1386.94)	(2.87)
Unavailability of IPM	-7180.39*	764.73	2.774
technology	(3719.92)	(1033.59)	(2.44)
Labor of IPM	-9458.25***	397.89	8.63***
technology	(3534.64)	(1119.55)	(2.47)
Quality of IPM	2769.32	-3089.47* (1791.51)	-29.261**
technology	(3663.08)		(3.40)
Constant	42771.58***	-7142.61	38.34***
	(12421.70)	(4950.73)	(9.85)
Number of observations	298	298	298
R^2	0.32	0.25	0.38
F	5.97***	2.34***	10.34***

Standard errors are in parenthesis; Significance at ***<0.001, **<0.005, *<0.1

Source: Survey data

Mango farmers who had access to extension reported increased net mango incomes of 4397 Kshs/acre. The perceived unavailability of IPM and labor requirements in the use and maintenance of IPM technology reduced mango net income by 7180 Kshs/acre and 9458 Kshs/acre respectively. The negative perceptions on unavailability of IPM technology and high labor requirements are plausible considering that both reduce mango net farm incomes. Additionally, if farmers perceive IPM use to be labor intensive, they are discouraged from adopting the technology a decision that negatively impacts their income from mangoes. The result on IPM technology unavailability corroborates with the finding of Andrade *et al*. (2019) who reported that farmers only adopt those technologies that are readily accessible.

Farmers treated with MAT+ADT technology combination reported the highest reduction in the expenditure on pesticides (-7,226 Ksh/acre) followed by those treated with ADT (-6,188 Ksh/acre) and the reductions in both cases were statistically significant at the level. These results are in line with the findings of Preciados (2013) and Midingoyi *et al*., (2019) who reported decreased use of synthetic pesticides due to IPM technology adoption in mango production. Access to agricultural credit services reduced expenditure on synthetic pesticides by -3,075 Ksh/acre.

Additionally, the perceived quality of IPM reduced expenditure on synthetic pesticides by -3,089 Ksh/acre. The negative impact of access to credit on mango pesticides expenditure can be attributed to the adoption of mango fruit fly IPM technology that lowers pesticide use. The finding on the effect of access to credit is consistent with the study by Yigezu *et al*., (2018) which reported that access to credit increases the intensity of adoption of improved agricultural technologies hence reducing expenditure on pesticides.

Treatment of mango farmers with MAT+ADT significantly reduced the proportion of mango losses due to fruit fly infestation by 27 percent of the total mango production. Both categories of farmers who received ADT and MAT interventions also reported a decline in mango losses due to fruit flies' infestation by 30 percent of the total mango production. These findings are in line with Muriithi *et al*., (2016) who reported that the adoption of different IPM strategies reduces the proportion of mango losses due to fruit flies' infestation. Further, Wangithi *et al.*, (2021) reported that the use of different combinations of IPM technology packages led to a reduction in the magnitude of citrus yield losses.

Membership to mango production and marketing groups reduces mango losses due to fruit flies' infestation by 31 percent of the total mango produced. Furthermore, the perceived quality of IPM technology reduced the proportion of mango losses due to fruit flies' infestation by 29 percent of the total mango produced while, the perceived labor requirements in the use and maintenance of IPM technology increase the proportion of mango losses due to fruit flies' infestation by 8 percent of the total mango produced.

4.4 Conclusions and policy recommendations

This study evaluated impact of adoption of improved integrated pest management practices (IPM) on the suppression of mango fruit fly infestation in Embu County, Kenya. The study fitted a difference-in-difference model on a two-period panel dataset to measure the impacts of the intervention differentiated by three treatments on three outcome variables. These treatments included the auto-dissemination technique (ADT), male annihilation technique (MAT), MAT+ADT, and the control group. The three outcome variables that the study considered are; mango net income, expenditure on pesticides, and proportion of postharvest losses due to fruit fly infestation.

The results show that the treatment of farmers with an IPM strategy increases net mango incomes and, the farmers who received MAT+ADT recorded the highest increase in net mango income. Compared to the control group, IPM treatment reduced the expenditure on synthetic pesticides with MAT+ADT farmers reporting the highest reduction in expenditure on synthetic pesticides. Further, IPM treatment led to a reduction in the proportion of proportion losses due to fruit fly infestation and, MAT+ADT reported the highest reduction in the proportion of postharvest losses due to fruit fly infestation. The results further show that access to agricultural extension positively influences mango yield and education of the household head influencing net mango farmers' income. On the other hand, the quality of IPM had a negative relationship with expenditure on pesticides and, access to credit services had a negative influence on the proportion of mango losses.

The study recommends the integration of the auto-dissemination technique into the existing conventional fruit fly IPM components to enhance the suppression of invasive pest. Developing countries should invest more in fruit fly IPM technology to improve mango yield and net income and reduce expenditure on synthetic pesticides and the proportion of postharvest losses due to fruit fly infestation. Further, capacity building should also be enhanced by making IPM products available and affordable to improve net mango incomes and reduce the proportion of postharvest losses due to fruit fly infestation. Information dissemination through mango production groups is also key in reducing the use of synthetic pesticides. Policies that encourage more proactive information-seeking through agricultural extension officers and mango production groups should be developed.

CHAPTER FIVE: GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 General conclusions

Fruit-fly infestation is ranked as the most constraining factor in the production and marketing of mangoes due to the associated economic losses. To control this pest, mango farmers have used unsustainable management practices such as the use of broad-spectrum chemical pesticides and indigenous methods. International Centre for Insect Physiology and Ecology (*icipe*) developed and promoted a fruit-fly integrated pest management (IPM) practices which has five components so as to enhance sustainable suppression of fruit-fly infestation. In addition to the five conventional IPM components, *icipe* also developed an auto-dissemination technique (ADT) to enhance the effectiveness of the technology.

The main objective of this study was to evaluate the impact of adoption of improved IPM practices in the suppression of fruit-fly infestation among 149 mango growing household in Embu County, Kenya. The specific objectives were, to analyse the drivers of fruit-fly IPM adoption and dis-adoption, and to assess the impact of integrating ADT with the conventional IPM on mango net income, expenditure on pesticides and, on the proportion of post-harvest losses due to fruit-fly infestation. The study utilized a two-period panel data that was collected before the intervention was issued in 2019, and after the intervention was given in 2022.

The descriptive results showed that 59 percent of the respondents were adopters of IPM practices, 24 percent were non-adopters and 17 percent were dis-adopters. Additionally, 40 percent of the adopters were partial farm users while 29 percent were seasonal users of the IPM technology. Farmers who had discontinued the use of IPM technology cited the unavailability of the technology as the main reason for dis-adoption. Seasonal users of the technology reported limited awareness with regard to the timing on when to replace the lures as the main ground for seasonal use while partial-farm use of the technology was attributed to a lack of capital to procure and maintain the technology.

The empirical results showed that training, the perceived cost of IPM, contact with extension officers, group membership, and the gender of the household head positively influence the adoption of IPM practices in the suppression of mango fruit fly infestation. Further, the age of the household head and the unavailability of IPM products have a negative influence on the adoption of IPM technology. On the other hand, the education of the household head, age of the household head, farm size, and the perceived quality of IPM positively influence the hazard of exit from the adoption of the IPM practices.

The results on objective two showed that the treatment of farmers with an IPM strategy increases net mango incomes and, the farmers who received MAT+ADT reported the highest increase in net mango income. Compared to the control group, IPM treatment reduced the expenditure on synthetic pesticides with MAT+ADT farmers reporting the highest reduction in expenditure on synthetic pesticides. Further, IPM treatment led to a reduction in the proportion of postharvest losses due to fruit fly infestation and, MAT+ADT reported the highest reduction in the proportion of postharvest losses due to fruit fly infestation. The results further show that access to agricultural extension positively influences mango yield and education of the household head influencing mango net income. On the other hand, the quality of IPM had a negative relationship with expenditure on pesticides and, access to credit services had a negative influence on the proportion of mango losses.

5.2 Recommendations

5.2.1 Policy recommendations

IPM technology should be made easily accessible to promote sustained adoption and discourage dis-adoption, seasonal use, and partial-farm use. Building the capacity of mango farmers through training and access to extension services is necessary to enhance the adoption of this technology and discourage dis-adoption. This can be achieved through the intensification of information dissemination by extension officers and farmer groups on the importance of the technology. In addition, IPM products should be made easily accessible to farmers to enhance the sustained adoption of the technology.

This study recommends the integration of the auto-dissemination technique into the existing conventional fruit fly IPM components to enhance the suppression of the invasive pest. Developing countries should invest more in fruit fly IPM technology to improve mango yield and net income and reduce expenditure on synthetic pesticides and the proportion of postharvest losses due to fruit fly infestation. Further, capacity building should also be enhanced by making IPM products available and affordable to improve net mango incomes and reduce the proportion of postharvest losses due to fruit fly infestation. This can be achieved by reducing the taxation on IPM products, and manufactures packaging the products in smaller quantities that farmers can easily buy. For capacity building, peer-to-peer learning can be encouraged by using existing commodity groups to teach farmers the techniques, visit other areas where the techniques have worked to lobby county governments for facilitating support.

Information dissemination through mango production groups is also key in reducing the use of synthetic pesticides. Policies that encourage more proactive information-seeking through agricultural extension officers and mango production groups should be developed.

5.2.2 Recommendations for further research

While the findings of this study provide useful insights into the different classifications of IPM adoption, the study lacked enough data for empirical analysis of the last two classifications (seasonality and scale of IPM use in mango orchards). Therefore, further research should consider the empirical assessment of the determinants of the two IPM definition approaches.

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APPENDICES

Appendix 1: Questionnaire Modules for IPM Adoption and Impact Study

MODULE 1. HOUSEHOLD AND VILLAGE IDENTIFICATION

1.1 Household Identification	Code		1.2 Interview details	Code
1. County			14. Date of interview (dd/mm/yyyy):	/ / 2022
2.Sub-County			15. Time started (24 HR)	
3. Ward			16. Name of enumerator	
4. Location			17. Name of supervisor:	
5. Sub-Location:				
6. Village:				
7. Name of household head (three names):				
8. Sex of household head			1=Male	
9. Name of the respondent (three names):			GPS reading of homestead	
10. Sex of respondent			1=Male 18. Way point number	
11. Name of respondent's spouse			19. Latitude (North)	
12. Cell phone number of household head			20. Longitude (East)	
13.Cell phone number of the spouse:			21. Altitude (meter above sea level)	

MODULE 2: MANGO PRODUCTION AND MARKETING
MANGO PRODUCTION

How many mango trees do you have in your farm (use table below)?

	Mango varieties planted CODE 1	Total number of young trees (less than 3 years)	Total number of trees in production	Average trees spacing (Meters)
	C1	C2	C3	C4
1				
2				
3				
4				

CODE 1		
Apple Tommy Atkins Ngowe Kent	5. Van dyke 6. Keitt 7. Sensation 8. Haden	9. Sabine 10.Local varieties 11.Other (specify)_____

Do you intercrop mango trees [C1A] __________] YES=1 NO=0?
If YES to C1A, then how do you intercrop [C1B] _______________] 1=Intercrop with different mango varieties 2= Intercrop with other crops
What proportion of your total annual income comes from farm income? [C5] [_______%]
What percentage of your total annual income is from mango? [C6] [_______%]

KNOWLEDGE OF MANGO PESTS, DISEASES, CONTROL STRATEGIES AND CONSTRAINTS IN ACCESSING KEY INPUTS AND CROP PRODUCTION

Does fruit flies cause damage to your mango crop [C7] [_______] 1=YES; 0=NO
If YES, how severe do you believe fruit flies are in terms of effects on yield/quality of your mango crops [C8] [_______] 1=high, 2= Medium, 3=low
If YES, is fruit fly the *major* mango infesting pest? [C9] [_______] 1=YES; 0=NO
What proportion of the mango production do you believe you lose due to Fruit flies (pre- and post-harvest) *(Hint for enumerators: assuming all your production is represented by 10 seeds of maize, how many seeds would you pick as part of the loss associated with fruit flies; Use the number of given seeds out of 10 to get % loss)* [C10] _____%]?
How do you manage/ control the Mango fruit flies (start with the main management strategy)?
[C11] [______] [______] [______] [______] [_____]

MANAGEMENT STRATEGIES		
Spraying with synthetic insecticides Use of fruit fly traps Intercropping with other crops Intercropping different varieties Planting resistant mango varieties Planting disease/pest free materials	Cleaning the field/ orchard sanitation Burring infested fruits Bagging infested/fallen off fruits Bagging fruits while on the tree Using augmentorium for disposing infested fruits Smoking mango trees	Spraying of plant-based pesticides e.g. Neem, pyrethrum etc. Biological control (using other insects like parasitoids) Irrigation Pruning Early harvesting Other methods (specify) ________

Grafting trees with early maturing varieties	Using of bio pesticides for soil inoculation	

Do you use any indigenous/locally made methods for control/management of mango fruit flies? [C12] [____] 1=YES; 0=NO

If YES (Qn. 3.2.6), describe the indigenous method/s? [C13]

____

If YES (Qn. 3.2.6), do you think these indigenous/locally made methods you use are effective in management of fruit flies? [C14] [____] 1=effective; 2=not effective; 3= do not know/not sure

What is the main reason/motivation for using the above-mentioned management strategy? (CODES A) [C15] [_________] [_________] [_________]

CODE A		
Reduced labour Reduced health and environmental risks	Lower cost of production Increased Production	Increased income through sale of quality fruits Others (specify)___________________________

Do you know any farmer who is using any other indigenous/locally made method/s for control/management of mango fruit flies other than the one you have just mentioned? [C16a] [_____] 1=YES; 0=NO

If YES (Qn. 3.2.11), describe the indigenous method/s? [C16b]

____

If using synthetic chemicals (Qn 3.2.5), how effective are they for control mango pests and diseases? [C18] [________] 1=effective; 2=not effective; 3= do not know

Are there other pests that affect your mango crop? [C19] [____] 0=No 1=Yes

If Yes (Qn 3.2.14), list other pests that affect your mango crop starting with the most severe one (codes) Pests [C20] [____] [_____] [____] [____]

Mango insect pests		
Mango weevil White mango scale Mealybug	Thrips Mango fruit borer Mango leaf gall midge	Mango caterpillars Blue-striped nettle grub Other specify________________

What proportion of the mango production do you believe you lose due to all other pests (less fruit flies) *(Hint for enumerators: assuming all your production is represented by 10 seeds of maize, how many seeds would you pick as part of the loss associated with fruit flies; Use the number of given seeds out of 10 to get % loss)* [C21] [_______%]?

Do you know any diseases that affect your mango crop? [C22] [____] 0=No 1=Yes

If Yes (Qn 3.2.17), list the disease that affect your mango crop starting with the most severe one (codes) [C23] [__] [___] [__] [___]

Mango diseases		
1.Anthracnose 2.Powdery mildew	3.Bacterial black spot 4.Sooty mould	5. Red rust 6.Other (specify)_____

What proportion of the mango production do you believe you lose due to all diseases [C24] *(Hint for enumerators: assuming all your production is represented by 10 seeds of maize, how many* *seeds would you pick as part of the loss associated with fruit flies; Use the number of given seeds out of 10 to get % loss)* [_____%]?

IPM KNOWLEDGE, SOURCES OF INFORMATION, PERCEPTIONS, ADOPTION AND DIS-ADOPTION

Have you heard about NON-PESTICIDE practices for control of Mango fruit flies [C25] [____] 0=No; 1=Yes [*Enumerator: tick YES, if farmer already mentioned a non-pesticide method in 3.2.5]?*

Have you heard about Auto-Dissemination technique(C26) 0=No; 1=Yes [Hint to enumerators: Auto-Dissemination is a strategy whereby males fruit flies transfer bio-pesticides intoxicating their female counterparts and the males through interactions and social behaviors like mating)

If YES to 3.3.1(C27), complete the table below) (*Enumerator note: If farmer says NO, try to probe further by mentioning some of the practices listed below then repeat the question; if NO second time, go to Question 3.6.11*

Names of IPM component	Do you know [component] 1=yes; 0=no C28	How did you first learn about the component? Code A C29	Are you currently (LAST SEASON) using this component? 1=Yes 0=No C30	When did you start using this component? (YYYY) C31	Will you continue using this component in future 1=Yes 0=No C32	If No to C32, Give three main reasons why you will stop using the component Code B C33	If NOT USING currently or didn't use LAST SEASON, were you using and stopped? 1= Yes 0= No C34	If Yes to C34, when did you first use the component (YYYY) C35	If Yes to C34, when did you stop using the component (YYYY) C36	If YES to C34, Give the three main reasons why you stopped using it Code C C37	Do you know other farmers using this component? 1=Yes 0=No C38	If YES, how many farmers? C39
Use of												

fruit fly traps																
Auto-dissemination technique																
Intercropping with other crops																
Intercropping different varieties																
Planting resistant mango varieties																
Grafting trees with early maturing varieties																
Cleaning the field/orchard																

sanitation															
Burring infested fruits															
Bagging infested fruits															
Bagging fruits on the tree															
Using augmentorium for disposing infested fruits															
Smoking mango trees															
Using of bio-pesticides for soil inoculation															
Spraying of plant-based pestic															

ides e.g. Neem, pyrethrum etc.																
Biological control (using other insects like parasitosis)																
Irrigation																
Planting disease/pest free materials																
Pruning																
Early harvesting																
Other methods (specify) ________																

Codes A			Codes B		
1. icipe (trials/demos/field days)	6. KARLO (trials/demos/field days 7. Other Research Centre	10. Farmers field school	1. Not available in the market 2. High prices/cost	5. Lack of skilled labor to use it 6. Requires intensive labour to set up and monitor	9. Lack of enough land

2. Govt extension 3. Farmer Coop/Union 4. Farmer group 5. NGO/CBO	(trials/demos/field days 8. Agro-dealers 9. Fellow farmers	11. Radio/newspaper/TV 12. Other, Specify ….........	3. Lack of cash to buy it 4. Is not effective not prevent the pest/disease	7. No market for the crop 8.Small scale production/ does not sell	10. Theft during ripe stage 11. Wild animals spoil the crop 12. Other, specify…………….

Do you think the above non-pesticide practices for management of fruit flies are effective? [C40] [_____] 1=effective; 2=not effective; 3= do not know
If using Fruit fly traps (Q3.3.3), do you buy the traps (containers) or use home-made traps [C41] [____] 0=Homemade 1=Bought 2=Both
If using fruit fly traps, is the use partial-farm or whole-farm (C42) [_____] 1= partial-farm; 2=whole-farm
If partial use, what are the three main reasons for the decision (code B) (C43)
What acreage of land under mango production do you apply the fruit fly traps? 1=low scale (0.5-5ha); 2=medium scale (5ha-10ha); 3=large scale (Above 10ha) (C44)
About how many mature mango trees are occupied by this area? (45) _________
Please provide the following information for fruit fly trap use for the last three mango production seasons (C46)

Mango production season	Did you use fruit fly traps during this season? Yes=1, No=0
2019/2020	
2020/2021	
2021/2022	

What are the three main reasons for the seasonal use of fruit fly traps (C47) (Enumerators: Seasonal user is a farmer who used the traps in one production seasons and skipped another)- code B
With how many farmers do you share information about IPM or components of IPM in your area/village? [C48] [_______]
If you use Fruit fly traps/MAT, what period of mango season do you lay the first trap/s (with lure)? (codes) [C49] [_____]

1=At flowering	3=When fruit matures	5=Other(specify)______________
2=Beginning of fruiting	4=At fruit ripening	

How often do you replace the Bactrolure wig inside the fruit fly trap? (codes) [C50] [_____]

1=After every 4 weeks	3=After 6 months	5=Other(specify)______________
2=After every 8 weeks	4=After a mango season (from flowering to harvesting)	

How many traps do you have currently/ had last season in your farm? [C51] [_____]?
Do you face the following constraints while using the non-pesticide methods for management of Fruit flies that you mentioned in Qn. 3.2.5 and Qn. 3.3.2 (*Enumerator note: Only ask the ones that the farmer is aware about or using as given in Qn. 3.2.5 and Qn. 3.3.2; Constraints mentioned in 3.3.2 can be transferred here without asking the farmer the same question again)*

IPM availability, training and quality Constraints	Is this a constraint in your mango production? 1=Yes 0=No 2=N/A
C52	C53
Availability of IPM components below	
Fruit fly traps / Male annihilation technique (MAT)	
Food bait spray	
Augementorim for orchard sanitation	
Bio pesticides for soil inoculation	
Biological control using parasitoids	
Disease free planting materials from certified nurseries	
2. Cost of purchasing the IPM components below	
Fruit fly traps / Male annihilation technique (MAT)	
Food bait spray	
Augementorim for orchard sanitation	
Bio pesticides for soil inoculation	
Disease free planting materials from certified nurseries	
3.Training of non-pesticide methods	
4. Support from government agricultural extension agents	
Quality of IPM components	
Fruit fly traps / Male annihilation technique (MAT)	
Food bait spray	
Augementorim for orchard sanitation	
Bio pesticides for soil inoculation	
Disease free planting materials from certified nurseries	
Auto-dissemination technique	
Labour for implementing and managing the non-pesticide fruit fly management methods	

Have you or any other member of the household received any training on Mango crop management in the last two years? [C54] [_____] 0=No, 1=Yes

If YES (Qn. 3.3.11), complete the table below

Type of training received C45a CODE A	Who offered the training? C45b CODE B	CODES A		CODES B	
		1.Pest and disease management 2.Soil and water use 3.Chemical handling 4.Product handling	5. Record keeping 6. Field hygiene 7.Chemical application 8.Others (specify) ____	1. icipe 2. Govt extension agent 3. Farmer Coop/Union 4. Farmer group 5. NGO/CBO	6. KARLO 7. Agro dealer 8. Fellow farmers 9. Other, Specify….........

Have you or any other member of the household received any training on IPM? (C55)[_____] 0=No, 1=Yes

MODULE 4: CROP PRODUCTION <u>FOR MANGO CROP GROWN</u> BY THE HOUSEHOLD DURING THE 2021/2022 CROPPING

Please provide the following information about the land used by the household in the last 12 months (also include rented land, and fallow/ grazing land)

Total owned land in acres, including fallow and grazing area D1	Rented-in (Acres) D2	Size Cultivated in 2018/2019 D3	Area under mango (Acres) D4

Inputs use in mango production during the last 12 months, 2021/2022 season

Did you use fertilizer on mango production during the last 12 months (DAP, NPK, CAN, UREA, MAVUNO etc) [D5] [______] 1=YES 0=NO

If YES (Qn 4.2.1, how much money did you spend on fertilizer [D6] [_______KES]

Did you use manure for mango production during 2021/2022 season? [D7] [_____] 1=YES 0=NO

If YES (Qn. 4.2.3), was it bought or own? [D8] [______] 0=Own 1=Bought 2= Gifted/given

If bought manure (Qn. 4.2.4), how much did you spend for the last 12 months [D9] [______] KES

Did you use chemical insecticides on mango production in the last 12 Months, 2018/2019 [D10] [______] 0 =NO 1=YES

If YES (Qn. 4.2.6), how much was spent on chemical insecticides [D11] [_____] KES

Did you use fungicides on mango production in the last 12 months, 2021/2022 season [D12] [______] 0 =NO 1=YES

If YES (Qn. 4.2.6), how much was spent on mango alone [D13] [_____] KES

Did you use herbicides on mango production in the last 12 months, 2021/2022 season [D14] [______] 0 =NO 1=YES

If yes, how much did you spend in the last 12 Months on mango alone 2021/2022 season [D15] [_____] KES

Provide the following information on labor required for MANGO agricultural operation for 2021/2022 cropping season

Mango production activities	Used hired labor 0=NO 1=YES [D16]	If yes, how much money was paid (KES) [D17]
Digging/Ploughing		
Manure application		
Fertilizer Application		
Weeding		
Pruning		
Chemical application (All)		
Bagging		
Orchard Sanitation		
Harvesting		
Top working/ grafting		
Irrigation		

What is the cost of hiring casual (farm) laborer in your village (KES/day) [D18] [_________]?
How many hours in average does the casual (farm) laborer work for the pay give in Question 4.4.1? (D19) [___________hours]?
Utilization and Marketing of mango in 2021/2022season
Provide the following information on Utilization & Marketing of Mango in 2021/2022 SEASON

		Total production		Total quantity sold			Total consumed at home		Gift/donation		Post-harvest loss				
	Mango varieties	Qty D20a	Unit Codes A D20b	Qty D21a	Unit Codes A D21b	Price per unit D21c	Qty D22a	Unit Codes A D22b	Qty D23a	Unit Codes A D23b	Qty D24a	Unit Codes A D24b	Main buyer Codes B D25	Codes C Why choose this market channel? D26	Actual transport cost (KES) D27
1	Apple														
2	Tommy Atkins														
3	Ngowe														
4	Kent														
5	Van dyke														
6	Keitt														
7	Sensation														

8	Haden													
9	Sabine													
10	Local varieties													
13	Other (specify)													

CODES A			CODES B		CODES C
1=pieces 2=crate 3=4kgs carton 4= 6kgs carton	5=17kgs bucket 6=50 kgs bag 7=90kgs bag 8=120 kg bag	9=Quintal (1Qt=48.95Kgs) 10. Other (specify)	1. Farmer group 2. Farmer Union or Coop 3. Consumer or other farmer(s) 4. Local trader	5. Non-local trader 6. Exporter 7. Other, specify…….	1. Better prices 2. Near the farm 3. They don't sort/grade 4.Others, specify

Do you have a contract for Mango production/ marketing? [D2] 8[__________] 1. Yes 0.NO

MODULE 5: INCOME FROM OTHER CROP PRODUCTION (OTHER THAN MANGO) GROWN BY THE HOUSEHOLD DURING THE 2021/2022 CROPPING SEASON (cropping season (*short rain* - Sep/Oct 2021 and *Long-rain*- Feb/March 2021)

5.1 Provide the following information on other crops (OTHER THAN MANGO) produced by the households DURING THE 2021/2022 CROPPING SEASON

Crop CROP CODES)	Total Quantity produced		Total quantity sold			Cash received income in KES E3a	Cash income (less inputs) in KES E3b
	Quantity E1a	Unit Code 1 E1b	Quantity E2a	Unit CODE 1 E2b	Market price per unit [E2c]		

CROP CODES	CODE 1

1. Arrowroots 2.. Avocado 3. Banana 4. Butternut 5. Cabbage 6. Capsicum 7. Carrot 8. Cassava 9. Chicken pea	10. citrus 11. Coffee 12. Common beans 13. Cowpeas 14. cucumber 15. Finger millet 16. Flowers 17. Irish potatoes 18. Kales	19. Khat 20. Lentils 21. local vegetables 22. Maize 23. Mango 24. Nappier 25. Nuts 26. Onions	27. Pawpaw 28. Pepper 29.Pigeon peas 30. pumpkins 31. Rice 32. Sorghum 33. Soyabean	34. Sugarcane 35. Sunflower 36. Sweet potato 37. Tobacco 38. Tomatoes 39. Trees 40. Water Melon 41. Others, Specify	1=pieces 2=crate 3=4kgs carton 4= 6kgs carton 5=17kgs bucket 6=50 kgs bag	7=90kgs bag 8=120 kg bag 9=Quintal (1Qt=48.95Kgs) 10.Kgs 11. Other (specify)

MODULE 6: PROVIDE THE FOLLOWING INFORMATION ON LIVESTOCK OWNERSHIP & MARKETING THE LAST 12 MONTHS

6.1 How many adult animals do you own currently (including Indigenous cows, cross bred/exotic cows, Oxen, Bulls) [F1] [______]

6.2 How many small livestock do you own currently (calves, goats and sheep) [F2] [_______]?

MODULE 7: SOCIAL CAPITAL, NETWORKING AND ACCESS TO CAPITAL AND INFORMATION

7.1 Are you or any other household member currently a member of any mango production and marketing association group? [G1] [____] 0=No; 1=Yes

7.2 Are you or any member of any rural institutions/group? [G2] [____] 0=No 1=Yes

7.3 If Yes (Qn.7.1), what type of rural instirtutions/ groups is/are they it? [G3]Code A [______] [______] [_____][______]

Code A: Institution Type		
Savings and credit association Merry-go-round Input supply group, farmer cooperative union Crop or seed production group	Water User's Association Crop marketing group Women's Association/group General farmer's association	Youth Association/group Church/mosque association/ congregation/ faith-based association Development group (*nyumba kumi*) Other specify_____

7.4 In the last 12 months, did your household need credit for mango production or any other agricultural activities? [G4] [____] 0=No 1=Yes

7.5a If Yes (Qn. 7.4), did your household receive the credit they need? [G5] [____] 0=No 1=Yes

7.5b.1 If YES to (Qn. 7.5), Why didn't the household receive the credit needed? [G5A] _________]

CODES

1. Borrowing is risky 2. Interest rate is high 3. Too much paper work/procedures 4. Expected to be rejected, didn't try 5. I have no asset for collateral 6. No money lenders in the area for this purpose 7. Lenders don't provide the amount needed 8. No credit association 9. Not available on time 10. Other, specify

7.6 How easy is it for you to get good information about new agricultural technologies/practices? [G6] [______] 1*) Very easy 2) Easy 3) Difficult 4) Very difficult*

7.7 Did you receive information/advice from (government) extension officers in the past 12 months? [G7] [____] 0=No 1=Yes

MODULE 8: HOUSEHOLD INCOME FOR THE LAST 12 MONTHS

8.1 What was your household's income from the following sources during the past 12 months?

Income source	Did the household earn income? 0=No; 1=Yes	Total income for the past 12 months		
		Cash (KSh)	In-kind (cash equivalent in (KES)	Total (KES)
	H1	H2	H3	H4
Income from salaried employment (salaries from non-agricultural employment) (e.g. civil service)				
Wages from labour from other farms (e.g weeding, ploughing etc)				
Wages from casual labor (off-farm)				
Income from machinery services for other farms (plowing etc.)				
Income from own non-agricultural businesses (shops, saloons, masonry, carpentry, handicrafts etc)				
Income from non-farm agribusiness (grain milling, grain trading etc)				
Sale of charcoal, firewood, brick making, selling firewood etc				
Sale of animal manure				
Sale of wild fruits				
Petty trade (net profit)				
Remittances from family members/friends who do not live in the household				
Revenues from leasing/renting out land				
Gifts (kind/cash)				
Other sources (specify)…………				

MODULE 9: HOUSEHOLD COMPOSITION AND CHARACTERISTICS AND HOUSING CONDITIONS

9.1 HOUSEHOLD COMPOSITION AND CHARACTERISTICS (Household members-persons who live and eat together from the same pot (share food), including hired labour, students and spouse living and working in another location but excluding visitors)

ID CODE	Name of household member [Start with respondent]	Sex 1=M 0=F	Relationship to the household head CODE 1	Age (complete years)	Marital status? CODE 2	Education (years) CODE 3	Primary occupation CODE 4	Labor contribution to farms cultivated by household in 2018/2019 CODE 5
	J1	J2	J3	J4	J5	J6	J7	J8
1								
2								
3								
4								
5								
6								

CODE 1		CODE 2	CODE 3	CODE 4		CODE5
1.Household head 2.Spouse 3.Son/daughter 4.Parent 5.Son/daughter-in-law	6.Grandson/granddaughter 7.Other relative 8.Hired worker 9.Other, specify……………	1.Married living with spouse 2.Married living without spouse 3.Divorced/separated 4.Widow/widower 5.Never married	0. None/Illiterate 1. Adult education or 1 year of education * Give other education in years (e.g. 2 yrs for std 2, 8 yrs for class 8 etc	1.Farming (crop+ livestock) 2.Salaried employment 3.Self-employed off-farm 4.Casual labour	5.Casual labouer off-farm 6.School/college child 7.Non-school child 8.Other, specify……………..	1. Full time 2. Part time 3. Not a worker

Appendix 2: DiD estimates of the unconditional treatment effects of fruit fly IPM adoption on outcome variables among mango farmers in Embu, Kenya

	Net Mango Income (Ksh/acre)	Expenditure on Pesticides (Ksh/acre)	Proportion of Fruit fly Losses (Percent of total production)
Time	14961.76***	-1319.17	-19.83***
	(4315.68)	(4704.334)	(3.77)
Auto-dissemination technique (ADT)	6888.27	-5531.084***	-0.49
	(6895.43)	(1859.195)	(3.65)
ADT*Time	27662.85***	-7376.17*	-32.33***
	(10297.39)	(4224.27)	(5.05)
Male annihilation technique (MAT)	10870.56*	908.36	0.90
	(5888.96)	(1975.34)	(2.89)
MAT*Time	21315.38***	-4151.40	-30.07***
	(9068.99)	(2793.56)	(4.49)
MAT+ADT	-3286.53	504.00	10.19***
	(4457.80)	(2331.14)	(3.44)
(MAT+ADT) *****Time	46613.70***	-6614.18**	-27.73***
	(8747.72)	(3296.73)	(4.893)
Constant	22674.52***	4405.75***	28.55***
	(3223.64)	(1473.18)	(1.99)
Number of observations	298	298	298
R-squared	0.25	0.25	0.29
F	12.58***	2.34***	34.15***

Standard errors are in parenthesis; Significance at ***<0.001, **<0.005, *<0.1

Source: Author's survey data (2022)

Appendix 3: Fixed effect estimates of the effects of fruit fly IPM adoption on outcome variables among mango farmers in Embu, Kenya

	Net Mango Income (Ksh/acre)	Expenditure on Pesticides (Ksh/acre)	Proportion of Fruit fly Losses (Percent of total production)
Time	-16954.129	-302.71	25.137**
	(18499.86)	(395.27)	(12.29)
Auto-dissemination technique (ADT)*Time	28073.63***	-5188.24**	-29.198***
	(6684.45)	(2010.12)	(5.22)
Male annihilation technique (MAT)*Time	22451.28***	-5023.07*	-29.95***
	(6019.39)	(2036.08)	(4.15)
(MAT+ADT) ***Time**	46614.36***	-4919.12***	-27.82***
	(6915.15)	(1061.57)	(4.55)
Education	798.06	-328.77	-0.19
	(714.84)	(146.61)	(0.61)
Age	-167.70	470.38	1.86
	(1450.44)	459.01	(1.93)
Extension	8146.26*	-1416.16	-5.95*
	(4723.31)	(1698.43)	(3.46)
Group membership	6567.03	-289.85	-1.12
	(9700.05)	(2650.83)	(4.62)
Credit	5290.57	-1763.49	-1.36
	(6138.38)	(1457.35)	(3.31)
Unavailability of IPM	-1423.81	628.21	4.54
	(5415.03)	(957.94)	(4.50)
Labor of IPM	-8318.34*	2521.93	6.48*
	(4751.99)	(1956.82)	(3.90)
Quality of IPM	1256.32	-666.71*	-10.62**
	(4386.68)	(1570.05)	(4.84)
Constant	3714551.70	-1797037.30	2919.73
	(3997658.40)	(1222339.30)	(4949.74)
Number of observations	298	298	298
R-squared	0.26	0.08	0.44
F	2.58***	2.47**	5.87***

Standard errors are in parenthesis; Significance at ***<0.001, **<0.005, *<0.1
Source: Author's survey data (2022)