Impact of Adoption of Integrated Pest Management Practices on the Suppression of Mango fruit fly Infestation in Embu County, Kenya

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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 165 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 services on mango farmers' net income. The study recommends the integration of ADT 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.

Keywords: Integrated Pest Management, Male Annihilation Technique, Auto-dissemination Technique, Difference in Difference

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 employing approximately 200,000 small-scale farmers (HCD, 2017; Wangithi *et al*., 2021). On 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 for 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 disease 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). The fruit fly 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 enhance its effectiveness in suppressing pests (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, and 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 (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 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 knowledge gap, 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 the 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 three outcome variables (that is 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 four 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. The remainder of this paper is organized as follows; section 2 presents the study's methods, section 3 results and discussions. Finally, section 4 provides some conclusions and policy recommendations.

2. Study Methods

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:

$$U^{a} = X' \beta_{ipm} + \varepsilon_{ipm} \quad (1)$$

$$U^{n} = X' \beta_{ipm} + \varepsilon_{ipm} \quad (2)$$

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 observed 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 the adoption of new technologies such as IPM can help to increase mango net income, and 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;

$$Y_{ipm} = X \infty_{ipm} + \delta S_{ipm} + \mu_{ipm} \quad (3)$$

Where Y_{ipm} represents the outcome variables of interest, X the explanatory variables, S the IPM treatment, ∞ 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 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.

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;

$$y_i = \alpha + \theta t + \beta_1 MAT + \tau_1 t * MAT + \beta_2 ADT + \tau_2 t * ADT + \beta_3 ADTMAT + \tau_3 t * ADTMAT + \gamma X_i + \varepsilon_i \quad (4)$$

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);

$$y_i = \theta t_{it} + \tau_1 t * MAT + \tau_2 t * ADT + \tau_3 t * ADTMAT + \gamma X_i + \eta_i + \varepsilon_i \quad (5)$$

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

2.3 Data sources and sampling procedures

The data utilized in this study were collected from a sample of 165 mango-growing households in Embu County shown in Figure 1. The county was chosen owing to its high mango production volume (HCD, 2017) and given that it is one of the sites where the African Fruit Fly Program has been implemented by *icipe* since its inception in 2012. The county lies between 1000 and 2070 meters above sea level. The agriculture sector plays an important role in the county as it contributes to over 70% of the county's economic base. The data were collected over two time periods, the baseline survey before treatment in 2019 and the follow-up survey after treatment in 2022. The "treatment" involved availing the improved mango fruit fly IPM technologies to some farmers and leaving out other farmers (the control).

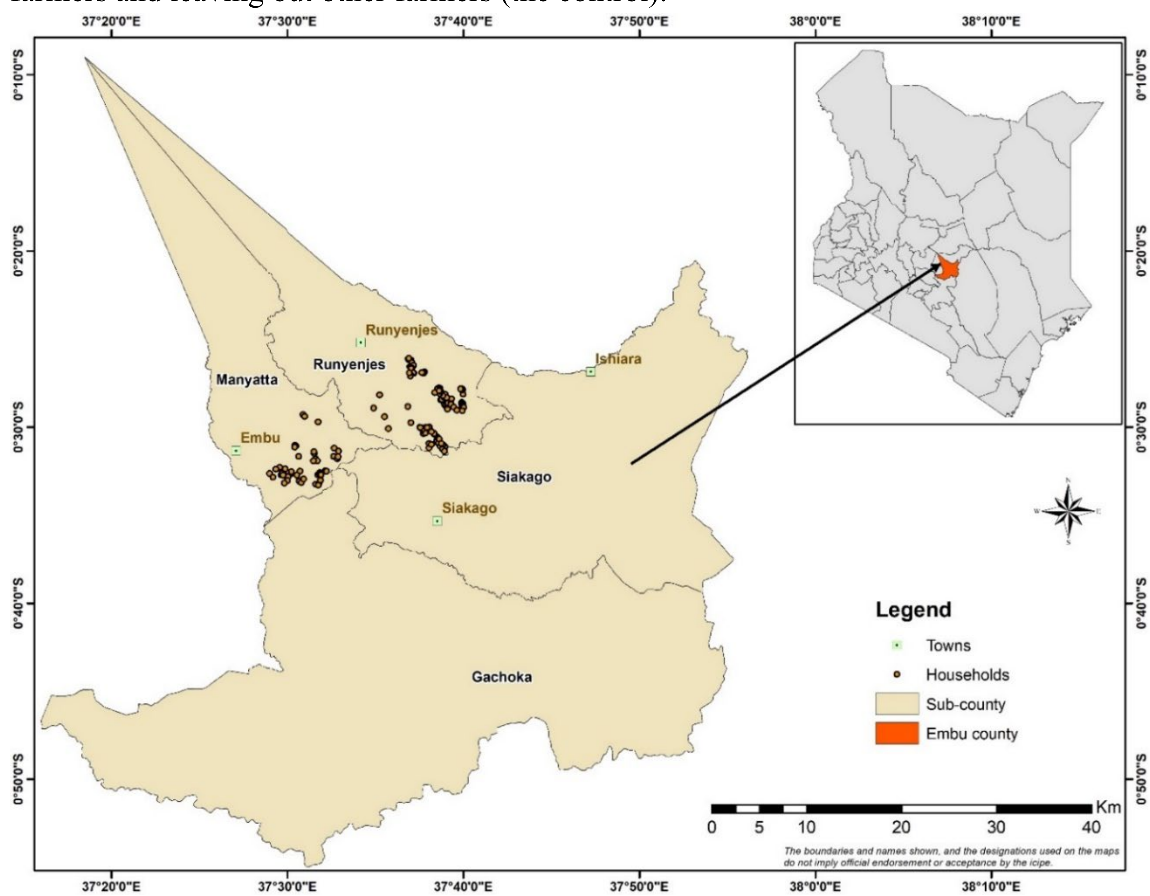

Figure 1: Map of the study area

Source: Wangithi *et al*., 2021

The baseline survey conducted by Wangithi *et al*., (2021) in 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 owing to their relative importance in mango production in the County. In the second stage, a simple random sampling technique was used to select 165 mango farmers in 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 introduced to the treatment 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 attained 149 households and, the 11 percent non-response was attributed to attrition as some baseline farmers relocated to other counties. The data were collected using a semi-structured questionnaire programmed in the Census and Survey Program System (CSPro). The data were collected through face-to-face interviews with enumerators who were trained and supervised by the research team. 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 analyzed in STATA version 16.

2.4. Definition and measurement of variables

Literature on the adoption of agricultural technologies including fruit fly IPM technology adoption guided the choice of the explanatory and outcome variables used in this study (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 three dependent variables for this study included mango net income, total expenditure on chemical pesticides, and the proportion of postharvest losses from fruit fly infestation (Table 1).

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 total mango pesticide expenditure was evaluated as the total cost of pesticides per unit of mango production (Kshs/acre).The proportion of postharvest losses was estimated as the output of damaged mangos due to fruit fly infestation as a share of the total output of mangoes per farm (percentage).

Table 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	Whether the unavailability of IPM is a constraint in the adoption 1=yes, 0=No	−/+
Labor of IPM	Whether labor requirement in the use and maintenance of IPM is a constraint in the adoption 1=yes, 0=No	−/+
Quality of IPM	Whether the quality of IPM is a constraint in the adoption 1=yes, 0=No	−/+

Gender was represented as a dummy variable with male-headed households being assigned a value of one, zero otherwise. The age of the household head and their educational achievement were captured in years. Access to extension was represented as a dummy variable with farmers who had been visited by an extension in the year before the survey being assigned a value of one, zero otherwise. Group membership was a dummy variable taking the value of one if a farmer belonged to a mango production and/or marketing group, and zero otherwise. Access to credit was a dummy variable with a value of one for farmers who accessed agricultural credit services and zero otherwise. Farmers' perception of whether the unavailability of the IPM technology was a constraint to the technology's adoption was elicited as a dummy variable taking the value of one for farmers who perceived it as a constraint zero otherwise. Farmers' evaluation on whether labor was a constraint in the adoption of the IPM technology was elicited as a dummy variable with a value of one for farmers who perceived labor requirements in the use and maintenance of IPM to be a constraint, zero otherwise.

The metadata was disaggregated into four datasets before implementing the DiD model. Before the analysis, the treatment and time variables were defined and, a new interaction variable between time and treatment was generated. On each dataset, preliminary validity checks of multicollinearity and heteroskedasticity were conducted. The Stata diff. command was implemented on each dataset after defining the time and treatment variables to establish the unconditional treatment effects. Finally, the DiD model was implemented using the Stata reg command and included the treatment, time, and interaction term variables and, other contextual variables to establish the conditional treatment effects for each outcome variable.

3. Results and discussions

3.1 Descriptive results

The farm, farmer, and IPM technology-specific characteristics of mango framers in Embu County are presented in Table 2. A test of the difference of means across the treatment groups was conducted using the F-test.

Table 2: Sociodemographic profiles of mango Farmers in Embu County, Kenya

Explanatory Variables	**Male annihilation technique (MAT)**	**Auto-dissemination technique (ADT)**	**MAT+ADT**	**Control**	**F test**
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	0.39	0.47	0.48	0.48	0.68
Labor of IPM	0.28	0.32	0.23	0.52	6.54***
Quality of IPM	0.33	0.40	0.46	0.57	2.41*

Source: Authors' survey data (2022)

Note: *p < 0.1, **p < 0.05, ***p < 0.01

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. 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. The summary statistics of the three mango production outcome variables across the different treatment groups are presented in Table 3.

Table 3: Net 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-test**
Net Mango income (Kshs/acre)	36,721.90 (3,988.83)	35,913.34 (4,798.12)	35,213.96 (4,353.82)	15,193.64 (2,252.87)	28,064.98 (1,886.63)	10.27***
Pesticide Expenditure (Kshs/acre)	4,366.98 (665.43)	3,229.18 (1,145.22)	2,731.23 (515.14)	5,534.32 (1.142.48)	4,338.27 (507.29)	1.58
Proportion of fruit fly postharvest losses (Percent)	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: Authors' survey data (2022)

An F test with Bonferroni-adjusted significance was run to test for overall statistical differences in means across and between four groups. 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.

3.2 Econometric results

Table 4 presents the DiD estimates of the impacts of the adoption of IPM technology on the suppression of mango fruit fly infestation in Embu County, Kenya. Before estimation, the data were tested for multicollinearity and heteroskedasticity. Results from the variance inflation factor (VIF) and the tolerance level (TL) tests as well as the Pearson partial correlation coefficient test show that multicollinearity was not a major problem in the data. To test if the error variance was not changing over a range of measured values, the Breusch-Pagan test was conducted and the results confirmed that the error variance was constant.

Table 4 presents the results of the conditional treatment effects. To evaluate the conditional treatment effects of the mango fruit fly IPM technology packages, the DiD was implemented with the farm, farmer characteristics, and, technology-specific characteristics controlled for. The outcome measures have been captured in columns 2 – 4 of Table 4 starting with net mango income, expenditure on pesticides, and proportion of postharvest losses due to fruit flies.

Table 4: DiD estimates of the impacts of adoption of IPM practices in the suppression of mango fruit fly infestation in Embu County, Kenya

	Net Mango Income (Kshs/acre)	**Expenditure on Pesticides (Kshs/acre)**	**Proportion of Fruit fly Losses (Percent of total production)**
Time	2,344.93*	-302.71	-0.68
	(1,268.69)	(395.27)	(0.73)
Auto-dissemination technique (ADT)	10,366.70	930.32	-1.29
	(6,868.45)	(2,657.38)	(4.25)
ADT*Time	26,552.02***	-6,188.24**	-30.36***
	(9,671.05)	(2,010.12)	(5.22)
Male annihilation technique (MAT)	3,364.55	1,333.36	3.24
	(5,559.92)	(1,376.87)	(3.14)
MAT*Time	24,424.78***	-3,804.69	-30.26***
	(9,034.54)	(2,403.04)	(4.51)
MAT+ADT	-5,598.30	1,041.07	12.25***
	(4,653.42)	(1,287.34)	(3.78)

(MAT+ADT) *Time	42,960.68***	-7,226.51**	-27.18***
	(8,824.21)	(3,360.54)	(4.90)
Gender	2,918.46	-635.30	-1.31
	(3,866.70)	(1,084.14)	(2.43)
Education	1,196.87**	-183.90	-0.02
	(557.14)	(90.93)	(0.27)
Age	-438.45***	10.52	0.04
	(156.42)	(33.02)	(0.10)
Extension	4,397.21***	-1,244.27	-30.30***
	(3,903.94)	(1,075.43)	(2.01)
Group membership	5,078.10	-7,265.96	-31.23*
	(6,940.80)	(4,359.66)	(2.69)
Credit	3,364.25	-3,075.03**	-0.13
	(4,866.54)	(1,386.94)	(2.87)
Unavailability of IPM	-7,180.39*	764.73	2.774
	(3,719.92)	(1,033.59)	(2.44)
Labor of IPM	-9,458.25***	397.89	8.63***
	(3,534.64)	(1,119.55)	(2.47)
Quality of IPM	2,769.32	-3,089.47*	-29.261**
	(3,663.08)	(1,791.51)	(3.40)
Constant	42,771.58***	-7,142.61	38.34***
	(12,421.70)	(4,950.73)	(9.85)
Number of observations	298	298	298
R-squared	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: Authors' survey data (2022)

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).

Mango farmers who had access to extension reported increased net mango incomes of 4,397 Kshs/acre. The perceived unavailability of IPM and labor requirements in the use and maintenance of IPM technology reduced mango net income by 7,180 Kshs/acre and 9,458 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 (2019) 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. Conclusions and policy recommendations

This study evaluated the impacts of adoption of IPM practices on the suppression of mango fruit fly infestation in Embu County, Kenya. The study fitted a difference-in-difference model on two-wave panel data 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 the IPM technology packages increases net mango incomes and that the farmers who received the MAT+ADT technology package recorded the highest increase in net mango income. Compared to the control group, mango fruit fly IPM technology treatments reduced the expenditure on synthetic pesticides with MAT+ADT farmers reporting the highest reduction in expenditure on synthetic pesticides. Further, IPM technology treatments led to a reduction in the proportion of mango 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 and education increased mango yields and net mango income respectively. 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 technology packages 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 be enhanced by making IPM technology packages 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.

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