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Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya

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ABSTRACT

We utilized two waves of data collected from a sample of mango farmers in Meru County in Kenya to evaluate the impact of Integrated Pest Management (IPM) strategy for controlling fruit flies in mango-production. We specifically explored the effect of five IPM practices including parasitoids (*p*) and *Metarhizium anisopliae*-based biopesticides (*biop*), orchard sanitation (*os*), spot spray of food bait (*fb*) and male annihilation technique (*mat*) on three outcome indicators: farmer pesticide expenditure, farm-level mango fruit yield losses and profit. We fitted difference-in-difference and household fixed effects regression models that account for unobserved heterogeneity across households. Our estimates differentiated the impact of the different IPM components, in comparison to farmers' practices as a control group. The descriptive statistics of the study show that application of the IPM strategy resulted in a 48% average increase in mango net income compared to the previous season irrespective of the IPM combination component used. The extent of improvement in net income, however, varied across treatments; treatments *posfb* and *posmatfb* registering the greatest improvements whereas the *pos* treatment generated the smallest increase in net income. The study findings further show mango yield losses due to fruit fly infestation reduced by an average of 19% among the IPM users. We also found a reduction in expenditure on pesticides, albeit across all the households. Regression model estimates show that, except for IPM combinations *posbiop* and *pos*, farmers using the rest of the IPM practices recorded significantly higher incomes from mango compared to their counterparts in the control group. We also noted that although average expenditure on pesticides decreased across all mango farmer households, the reduction was comparable between the treated and control farmer households. Our findings however, show significant decreases in mango damage due to fruit fly infestations among all farmers using the different IPM treatments. Our study recommends combinations of affordable and easy to apply and maintain IPM strategies that could yield significant impact on mango fruit fly control.

1. Introduction

Mango is an important food and cash crop enterprise, which plays an important role in the socio-economic development of the rural and urban populace in Sub-Saharan Africa (SSA) (Lux et al., 2003). In Kenya, the enterprise contributes significantly to the agricultural Gross Domestic Product (GDP) and foreign exchange earnings. For example, in 2011, mango exports to the regional market accounted for 32 and 8% in volume and value of total fresh fruits, respectively (United States Agency for International Development, USAID, 2011). Although the volume of mango produced has increased over the years, from below 250,000 metric tonnes in 2003 to over 750,000 metric tonnes in 2012 (USAID-KHCP, 2015), the productivity of mango in Kenya is still below its potential – estimated at 2.8 million metric tonnes (Horticultural Crops Development Authority, HCDA, 2013). High postharvest losses estimated at 40% of production reduce the volume of produce available for processing and for export markets (USAID-KHCP, 2015). Other major constraints hindering productivity are insect pests infestation particularly, tephritid fruit flies (e.g. *Bactrocera dorsalis* (Hendel), *Ceratitis cosyra* (Walker) etc), as well as diseases such as anthracnose and powdery mildew (Lux et al., 2003; Sebstad

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and Snodgrass, 2004; Ekesi et al., 2011; USAID-KHCP, 2013). Tephritid fruit flies cause direct damage by reducing mango productivity (Ekesi et al., 2006; Rwomushana et al., 2008) and quality, thus reducing the market value of the mangoes, and subsequently lowering revenues to farmers (Kibira et al., 2015). Moreover, quarantine restrictions on fruit fly-infested produce limit exports to lucrative markets abroad. For example, Seychelles, Mauritius and South Africa have banned export of host fruit species of the invasive fruit fly *B. dorsalis*, such as mango and avocado, from Kenya, Tanzania, and Uganda (Bech, 2008). Similarly, trade of several horticultural products between Africa and the US have been severely hampered by a US Federal Order banning importation of several cultivated fruits and vegetables from African countries where *B. dorsalis* has been reported (Bech, 2008). Therefore, fruit flies represent a major threat to current and future mango enterprises in Kenya and Africa in general.

Many farmers in developing countries, including Kenya, mainly rely on synthetic chemical pesticides to control insect pests such as fruit flies. The use (and misuse) of chemical pesticides is, however, often associated with high health and environmental risks (Brethour and Weersink, 2001; Macharia et al., 2008; Kouser and Qaim, 2013). Overuse of chemical pesticides is especially evident in the horticultural industry (Macharia et al., 2005, 2008; Asfaw et al., 2010), that has led to several interceptions of horticultural products, including mango fruits, in the international market (Lux et al., 2003). In addition, pesticides are expensive and often unaffordable to majority of resource poor farmers. Researchers advocate the use of Integrated Pest Management (IPM) as a more sustainable alternative to widespread broad spectrum chemical insecticidal application in developing countries (Norton et al., 1999). The IPM approach can generally be defined as the intellect selection and use of pest control actions that ensure favourable economic, ecological and sociological consequences (Blake et al., 2007). The IPM strategy is currently recommended for the management of fruit flies in Africa (Ekesi and Billah, 2007; Ekesi et al., 2011). The strategy minimizes the dependence on the use of chemical pesticides (Varela et al., 2006). Empirical evidence shows that investments in IPM programs generate positive farm returns. For example the IPM strategy has been associated with high rates of return to cotton production in several Asian countries (Erickson, 2004; Ooi et al., 2005), and to horticultural crops such as onions in the Philippines (Sanglestsawai et al., 2015).

In Africa, the International Centre of Insect Physiology and Ecology (ICIPE) has spearheaded development and implementation of IPM strategy for managing fruit flies on mango, under the African fruit fly program (AFFP). The goal of AFFP program is to reduce mango losses due to fruit fly infestation, lower the cost of production, increase income at the producer level and improve market access and processing through increased quality and productivity of mangoes, to meet the needs of both the domestic urban and export markets. The fruit fly IPM-based approach uses a combination of interventions that complement each other rather than work as a stand-alone management strategy (Ekesi and Billah, 2007; Ekesi et al., 2011; Korir et al., 2015). The fruit fly integrated IPM packages developed by ICIPE consist of: (1) spot application of food bait, (2) male annihilation technique, (3) use of biopesticide, (4) releases of parasitoids (*Fopius arisanus* (Sonan) and *Diachasmimorpha longicaudata* (Ashmead) (both Hymenoptera: Braconidae)) and (5) use of orchard sanitation. The strategy is being promoted widely across several African countries including Kenya. In the later country, the strategy has been implemented in the major mango growing regions of Coast and Eastern Counties. The ongoing fruit fly IPM strategy dissemination and promotional activities by the program shows clear indications of success with several growers rapidly taking up the strategy (Korir et al., 2015). However, Korir et al. (2015) revealed that mango growers adopt only particular IPM components instead of the whole IPM package. Possible reason for adoption of specific components could be attributed to lack of knowledge of the combination of IPM components that maximize benefits, both by the farmer and extension workers. Such empirical study that analyzes the impact of different combinations of IPM intervention packages do not exist. Kibira et al. (2015) attempts to analyse the impact of these IPM techniques, but does not disaggregate different IPM components. The objective of the present study was to evaluate the impact of application of the various combinations of the IPM strategy for managing mango-infesting fruit flies on pesticide expenditure, mango fruit yield loss and profit using two waves of panel data collected in one of the project action sites of Meru County, Kenya as a case study. The study adopted a quantitative economic impact assessment research approach thus providing more transparency and justification for the outcome results (Soliman et al., 2015). Specifically, the study implemented difference-in-difference and household fixed effects regression to account for unobserved heterogeneity across households.

2. Methodology

2.1. The intervention

The present study evaluated various combinations of the five components of IPM intervention package developed by ICIPE. The five components included (1) spot spray of food bait *(fb)*, (2) male annihilation technique *(mat)*, (3) *Metarhizium anisopliae*-based biopesticide application (*biop*), (4) releases of parasitoid – *F. arisanus* and *D. longicaudata* (*p*), and (5) use of orchard sanitation (*os)* with the Augmentorium. The augmentorium, is a tent-like structure made of durable netting material with mesh size that allows the emerging parasitoid wasps to escape back, while the young emerging flies are sequestered when the infested fruits are placed inside, thereby serving the double purpose of orchard sanitation and parasitoid conservation (Klungness et al., 2005).

The spray food bait is a proteinous food bait (DuduLure®) developed by ICIPE, and it is combined with an insecticide (spinosad). The food bait is applied as localized spots at a rate of 50 ml solution on 1 m^2 of mango canopy. Both the adult male and female fruit flies are attracted to the confined area on the canopy of the mango tree where the food bait is sprayed. The fruit flies ingest the bait along with the toxicant, which kill them before they infest the fruits (Ekesi et al., 2014; Ekesi, 2015). Application started when the fruits were at the “golf ball stage” and continued till the end of harvest. The male annihilation technique (*mat*) involved deployment of high density trapping stations consisting of a male lure (in this case *methyl eugenol*), combined with a toxicant (malathion) to trap and kill male flies; thus reducing their populations to very low levels that mating does not occur or is greatly reduced (Ekesi and Billah, 2007; Hanna et al., 2008). The application rate in this trial was 7 Lynfield trap stations per ha recharged after 6 weeks of exposure. The biopesticides were fungus-based formulations that targeted pupariating larval stages of the fruit flies and emerging adult, but did not have any effect on the beneficial parasitoids (Ekesi et al., 2005), instead it complemented them in significantly reducing the fruit fly populations. The biopesticide (*M. anisopliae*) was developed jointly by ICIPE and a private sector company (Real IPM Ltd, Kenya) and is available commercially as Campaign® for the management of different species of fruit flies and other insect pests (Ekesi et al., 2005, 2002; Ekesi and Billah, 2007). The biopesticide components targeted pupariating larvae and pupae stages of the fruit fly, and were applied as a soil drench at the rate of 15 ml per 20 l of water sprayed under the tree canopy. Two parasitoid species were used in this study; the egg-prepupal parasitoid *F. arisanus* and the larval-prepupal parasitoid *D. longicaudata*. The parasitoids attack the eggs and the larvae, respectively, of the target fruit fly species (predominantly *B. dorsalis*); they develop through the larval stages of their host and emerge as adults from the host puparia (Mohamed et al., 2008, 2010). The parasitoid wasps were released at the rate of 1000 adults per ha. The principal advantage of the parasitoids is that once established, they are persistent and do not require additional inputs from the farmer (Ekesi et al., 2005).

Orchard sanitation was achieved using an Augmentorium (Klungness et al., 2005). This is a tent-like structure that sequesters fruit flies that emerge from fallen rotten fruits collected from the field and deposited in the structure, while at the same time conserving their natural enemies by allowing parasitoids to escape from the structure through a fine mesh at the top of the tent. Fruit collection and dumping in the Augmentorium was done biweekly from the onset of fruit maturity to the end of fruit harvest. In the study location, over 96% of the fruit flies in the area were the dominant invasive *B. dorsalis*, with only negligible numbers of the native *C. cosyra*. This native species has been largely displaced by the invasive species (Ekesi et al., 2009).

Different IPM intervention components mentioned above were combined to form seven treatments with the parasitoid releases (*p*) and orchard sanitation (*os*) serving as the common intervention among the treatment combinations as follows:

- *Treatment 1* (***pos***) + use of male annihilation technique (***mat***),
- *Treatment 2* (***pos***) + application of food bait (***fb***),
- *Treatment 3* (***pos***) + biopesticide (***biop***),
- Treatment 4 (**pos**) + (**mat**) + (**fb**),
- Treatment 5 (**pos**) + (**fb**) + (**biop**),
- *Treatment* 6 (***pos***) + (***mat***) + (***biop***), and
- *Treatment 7* (***pos***) + (***mat***) + (***biop***) + (***fb***).

An eighth treatment ***pos*** *(parasitoid and orchard sanitation)* was redefined after the second round of survey, for households that were assigned to some of the above treatments but did not apply them when the project was initiated. The AFFP team that monitored the application of the treatments throughout the season confirmed this. The control group involved use of conventional fruit fly suppression measures, that is, cover spray application of chemical pesticides. The common pesticides used to suppress fruit flies in Meru County in both the control and treatment locations before the IPM intervention included: Agrinate (water soluble powder, active ingredients (ai) – Methomyl 90%), Actara (water dispersible granules, ai – Thiamethoxam 250 g/Kg), Bestox (emulsifiable concentrate, ai- Alpha-Cyphpermethrin 100 g/L), Bayleton (wettable powder, ai – Triadimefon 250 g/Kg), Bulldock (granular, ai – Beta-Cyfluthrin 25 g/Kg), Cyclone (emulsifiable concentrate, ai – Cypermethrin 10% w/v + Chlorpyrifos 35%w/v), Danadim (emulsifiable concentrate, ai – Dimethoate 400 g/L), Jackpot (emulsifiable concentrate, ai- Lambdacyhalothrin 50 g/L), Ogor (emulsifiable concentrate, ai – Dimethoate 40 g/L), and Thunder (oil dispersal, ai – Imidacloprid 100 g/L + Betacyfluthrin 45 g/L). Mango farmers in the treatment zone were randomly assigned to first seven treatments, which consisted of different combinations of the mentioned IPM interventions. The control group of mango farmers was randomly selected from another site with similar attributes to the treatment.

Our study is thus, based on a quasi-experimental impact evaluation design. Both the treatment and control households were interviewed before and after the intervention. One practical challenge in an impact evaluation research design is identifying a suitable counterfactual or control group. In the present study, for instance, there was need to ensure that there were no spill-over effects of the project from the treatment area to the control locale, especially parasitoids released for classical biological control of *B. dorsalis*. To safe guard against this, the control group was located 38 km away from the treatment area. However, for comparability, the control group was selected such that the socio-economic, climatic, and topographic characteristics were similar to the IPM treated area. Following the parasitoid releases, periodical monitoring of their spread was carried out to ensure they were evenly distributed within the treatment area especially during the period of the highest fruit fly attack on mango. The periodical monitoring also assured that the parasitoids did not spread to the control location within the release and experimental evaluation period.

2.2. Sampling and data description

The data utilized in this study was collected before and after the IPM intervention, from the two mango farmer categories (both treatment and control groups) in Meru County in Kenya. The sample of farmers was selected following a two stage-sampling framework. Four sub-counties in major mango production areas of Meru County were selected as study benchmark sites, where a census of mango growers in those sub-counties was carried out with the assistance of the county agricultural extension workers and an agribusiness NGO promoter (TechnoServe). The first stage involved selection of those sub-counties where mango are predominantly produced namely, Central Imenti, North Imenti, and South Imenti (treatment areas), and Tigania West (control area). Thereafter, using the census as the sampling frame, 153 mango farmers were randomly selected to receive each of the seven treatments. In the control area, 179 mango farmer households were randomly selected for interviews. The final sample sizes (for the control and treatment groups) were computed following the standard procedure outlined by Baartlett et al. (2001). The baseline survey was conducted in November and December 2013 referring to the preceding mango season (May 2012–April 2013).

The data were collected using pre-tested structured closed-form questionnaires. The questionnaires captured important variables related to mango production (e.g., mango yield, losses, input expenditure, profit, and marketing) as well as other contextual data. In each household, an interview was conducted with the person mainly responsible for agricultural decisions, often the household head, to ensure that the information collected was as accurate as possible. A total of 1223 mango farmer households were successfully interviewed in the 4 sub-counties. Upon completion of the baseline survey, the farmers received the various IPM components as described above, after being trained on how to implement them for fruit flies suppression.

A close monitoring of the implementation of treatments was done until the end of the harvesting season around April 2014 in order to ensure that treatments were applied adequately. A follow-up study targeting the same households interviewed at the baseline was conducted between May and June 2014, capturing information for the season May 2013–April 2014. A sample of 1122 mango farmer households was revisited during the follow-up survey, with a sample attrition of 8%. The households that were absent for the second interview were lost mainly due to mismatched household records during the baseline survey. Our final sample for the analysis was 828 households including 694 IPM farmers and 134 control farmers. The top row of Table 1 shows the distribution of households across different mango fruit fly IPM packages, and control groups. The treatments included a combination of the IPM strategy components, abbreviated as described in Section two above.

Table 1
Selected farm and household characteristics.

	Posbiop (*n* = 78) [1]	*Posfb* (*n* = 92) [2]	*Posfbbiop* (*n* = 67) [3]	*Posmat* (*n* = 112) [4]	*Posmatbiop* (*n* = 106) [5]	*Posmatbiopfb* (*n* = 68) [6]	*Posmatfb* (*n* = 89) [7]	*Pos* (*n* = 82) [8]	*Control* (*n* = 134) [9]
Gender of household head (1 = male,	1.2	1.1	1.2	1.2	1.1	1.1	1.2	1.2	1.2
2 = Female)	(0.4)	(0.3)	(0.4)	(0.4)	(0.3)	(0.3)	(0.4)	(0.4)	(0.4)
Age of household head in years	52.3	52.1	53.2	54.5	54.1	53.3	54.6	48.0***	55.8
	(13.1)	(11.6)	(12.8)	(12.2)	(13.1)	(13.7)	(13.9)	(14.3)	(13.3)
Education of household head in years of	9.3***	8.9**	8.9*	8.0	9.4***	9.0**	9.0**	8.4	7.6
schooling	(4.0)	(3.5)	(4.1)	(4.3)	(4.4)	(4.0)	(4.4)	(4.2)	(4.3)
Household size in adult equivalent	2.7	2.7	2.6	2.5	2.5	2.7	2.5	2.3***	2.7
	(0.9)	(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(1.0)
Ownership of non-agro business (1 = yes)	0.2	0.2	0.1***	0.2	0.2	0.3	0.2	0.3	0.2
	(0.4)	(0.4)	(0.2)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
Land under cultivation (acres)	5.8***	5.8***	5.2***	4.9***	6.2***	6.3***	5.1***	4.5***	3.1
	(5.3)	(5.3)	(3.9)	(3.2)	(5.7)	(5.0)	(3.6)	(3.0)	(3.0)
Land under mango (percent of cultivated	32.0***	31.2***	27.8***	28.8***	31.9***	33.5***	32.3***	26.9***	59.9
land)	(33.9)	(26.9)	(23.0)	(31.2)	(27.7)	(26.4)	(24.5)	(26.7)	(50.7)
Livestock owned in Tropical Livestock Unit	2.0	2.3**	2.3**	2.0	2.4***	2.3**	2.2**	2.2	1.7
(TLU)	(1.4)	(2.0)	(1.9)	(1.5)	(1.7)	(1.8)	(1.8)	(1.7)	(1.1)
Mango farming experience (years)	11.9***	10.8	10.4	11.8***	10.6	12.0***	12.1***	9.1	9.6
	(5.0)	(5.9)	(4.1)	(7.3)	(4.1)	(5.1)	(4.7)	(3.8)	(3.6)
Distance to the nearest market (Kms)	7.7	14.0***	12.5***	12.6***	10.7***	11.1***	10.1***	9.6***	4.6
	(9.2)	(21.7)	(20.1)	(16.5)	(9.6)	(14.5)	(9.2)	(8.8)	(7.9)
Received mango training in the last 12	0.8***	0.8***	0.7***	0.7***	0.8***	0.8***	0.8***	0.4	0.3
months (1 = Yes)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.5)	(0.5)
Received mango extension contact in the	0.5***	0.5***	0.5***	0.4***	0.5***	0.4***	0.5***	0.2	0.2
last 12 months (1 = Yes)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)
Percent improved mango	97.3	96.2	97.5	96.4	97.4	96.0	98.4	96.8	95.4
	(8.4)	(11.0)	(7.5)	(9.9)	(8.4)	(11.0)	(7.8)	(9.2)	(16.3)

Notes: The mean (and standard deviation) of the farm and household characteristics for the treatment are shown in Columns [1] through [8], and for the Control group (Column [9]). The tests for the equality of means are the bonferroni-adjusted significance of the difference between individual treatments and the Control group. The abbreviations for the IPM interventions are as follows: ***P*** = parasitoids release; ***os*** = orchard sanitation; ***fb*** = food bait; ***biop*** = biopesticides; ***mat*** = male annihilation technique. 1 acre = 0.405 ha. The exchange rate at the time of the survey was approximately 85 Kenyan Shillings (KSh)/US $.
Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.
Source: author's household survey.

2.3. Empirical strategy

Given the panel nature of our dataset, the before and after, and the with and without survey design, we employed difference-in-difference (DiD) model to estimate the difference between the observed mean outcomes for the treatment and control groups before and after the IPM intervention. The DiD estimator is obtained by comparing the change in outcome measures before and after the project for a treatment group to the change in outcome measures over the same period for a control group (Abadie, 2005; Imbens and Wooldridge, 2008; Khandker et al., 2010). The DiD model compares the changes in outcome over time and accounts for selection bias due to time-invariant and additive unobservable differences among treatment and control groups (Glewwe and Jacoby, 2000). The model can be used to analyse changes in farm performance such as net income, pesticide expenditure, and production loss due to pest infestation. The model is specified linearly as follows:

$$\begin{aligned} y_i = {} & \alpha + \theta t + \beta_1 posbiop + \Gamma_1 t^* posbiop + \beta_2 posfb + \Gamma_2 t^* posfb \\ & + \beta_3 posfbbiop + \Gamma_3 t^* posfbbiop + \beta_4 posmat + \Gamma_4 t^* postmat \\ & + \beta_5 posmatbiop + \Gamma_5 t^* posmatbiop + \beta_6 posmatbiopfb \\ & + \Gamma_6 t^* posmatbiopfb + \beta_7 posmatfb + \Gamma_7 t^* posmatfb \\ & + \beta_8 pos + \Gamma_8 t^* pos + \boldsymbol{\gamma} \boldsymbol{Z}_i + \varepsilon_i \end{aligned} \quad (1)$$

where i denotes household, y is the outcome measure of interest (net income, pesticide expenditure, or magnitude of mango damage as a result of fruit flies); t is a dummy variable equal to 0 for the baseline and 1 for the follow-up survey. The coefficient of time dummy, θ captured changes that occur over time that are independent of the fruit fly IPM strategy. *Posbiop*, *posfb*, *posfbbiop*, *posmat*, *posmatbiop*, *posmatbiopfb*, *posmatfb* and *pos* are dummy variables accounting for different IPM treatments and their respective coefficients $(\beta_1, \beta_{2,}, \ldots\ldots\ldots, \beta_8)$, capture initial differences in y between the treatment and control groups. The coefficients of the interaction of t with *posbiop*, *posfb*, *posfbbiop*, *posmat*, *posmatbiop*, *posmatbiopfb*, *posmatfb* and *pos* $(\Gamma_1, \Gamma_2, \ldots\ldots, \Gamma_8)$ isolated the effect of each treatment on y for the period between the baseline and follow-up. On the other hand, $\boldsymbol{Z}$ included exogenous observable covariates that may have had an influence on y. These included observable farm and household characteristics and other contextual variables that were likely to influence the outcome measures. These variables include gender, age and education of the household head, household size in adult equivalence, amount of land owned in acres, herd of livestock owned in tropical livestock units (TLU), access to extension service over the last 12 months, and the share of improved mango trees in the farm.

Whereas the DiD estimator controls for unobserved time-variant heterogeneity, it does not control for unobserved time-invariant individual heterogeneity which may be correlated with both the treatment and other unobserved characteristics. These factors include skills, motivation and entrepreneur capabilities of households that may affect both the outcome and adoption of the IPM strategies. For this reason, we implemented fixed effect model as a robust check for the DiD estimator. For fixed effect specification, we amended Eq. (1) as follows:

$$y_{it} = \theta t_{it} + \Gamma_1 t^*posbiop + \Gamma_2 t^*posfb + \Gamma_2 t^*posfb + \Gamma_3 t^*posfbbiop + \Gamma_4 t^*postmat + \Gamma_5 t^*posmatbiop + \Gamma_6 t^*posmatbiopfb + \Gamma_7 t^*posmatfb + \Gamma_8 t^*pos + \gamma \boldsymbol{Z_{it}} + \eta_i + \varepsilon_i \quad (2)$$

where η_i is the unobserved time-invariant individual heterogeneity that may be correlated with both the treatment and the unobserved characteristics ε_i. The rest of the variables and respective coefficients are as explained under Eq. (1). Notice that we dropped the respective dummy variables for the treatments when we moved from Eqs. (1) and (2) as they are also time invariant.

3. Results and discussion

3.1. Descriptive analysis

3.1.1. Farm and household characteristics

Table 1 reports summary statistics of selected variables for the surveyed households. Columns [1] through [8] presents the averages for households in different treatments for the two survey rounds, while column [9] present data for the control households. We used the Bonferroni test to determine the mean differences between individual treatments and the control group.

It can be seen from Table 1 that the gender and age of the household head did not differ significantly across most of the treatment groups and control sub-sample, except between households who received the *pos* treatment and control group with reference to age. Households that received the *pos* treatment were significantly younger than their counterparts from the control group. With regard to education, heads in households that received all the treatments except *pos* and *posmat* had significantly higher years of schooling than those in the control group. Education enhances the skills and ability to utilize information (Heltberg and Tarp, 2002), which may enhance adoption of innovations such as IPM strategies for suppression of mango fruit flies. Household size was of the same range across all the treatments (except for the households that received *pos* treatment) and control group; the average number of persons in a household that received *pos* was significantly less than that of their counterparts from the control group. A large household size may reflect more labour endowment needed for performing agricultural activities, including mango production In contrast, increase in household size has been found to increase pressure on land, thus reducing the volume of marketed surplus and market profits as subsistence needs become a priority over commercial activities for small scale farmers von Braun et al., 1994). With respect to asset ownership, households in the control group had significantly smaller land acreage and fewer numbers of livestock compared to those in different treatments. Experience in mango production appears to be comparable across the various treatments and the control group except for treatments *posbiop*, *posmat*, *posmatbiopfb* and *posmatfb*; farmers from these treatments had more experience relative to those in the control group. On average, farms of households who received treatments were located further from the nearest market, but had more access to information through extension contact compared to those in the control group.

3.1.2. Choice and measurement of the outcome measures

The impact of different combinations of fruit fly IPM components was evaluated based on the development objectives that the ICIPE-AFFP sought to achieve. These include improving mango income, reducing mango losses due to fruit fly infestation, and reducing expenditure on pesticides especially those for management of fruit flies. Net income from mango was computed as the total revenue above the variable costs, per unit land (acre in this study). Variable cost included the amount of money spent on pesticides including insecticides and fungicides, fertilizer and manure, labour (hired and family) and marketing costs also aggregated per acre of land. Mango losses were captured as the proportion of mango damage due to fruit fly infestation out of the total mango crop produced. We followed De Groote (2002) and Gitonga (2009) who defined economic loss of maize yield due to stem borer infestation and snow pea yield loss as a consequence of leaf-miner infestation, respectively, as the proportion of potential total yield. Further, our definition was guided by Vayssieres et al. (2009), who estimated mango loss as proportion of potential total yield which was comprised of mango loss at pre-ripening and ripening stages. Total mango yield, which included sales and home consumption, were based on farmer's estimates and divided with respective area planted to mango. Pesticide expenditure included the total cost of purchasing pesticides to control various pests and diseases per unit land during a specific season. Table 2 presents the summary statistics of the four outcome variables of interest. We present the average for the two survey rounds by treatment in the first row under each outcome measure, and then the average change between the two survey periods in the subsequent row. We present net income from mango in two forms: first, without deducting family labour, and then less imputed family labour, valued at the given wage rate per day in the area of study. We also present the share of pesticide cost to total mango sales (in the fourth row of Table 2).

We conducted the tests for the equality of means using the Bonferroni-adjusted significance of difference in the outcome variables between individual treatments (columns [1] through [8]) and the control group (column [9]). Results showed that the change in net income between the baseline and follow-up surveys for households who applied treatments *posfb and posmatfb* was positive, and significantly different from that of the control group. All the other treatments, however, exhibited increase in net income compared to the control group, although the difference was not significant. Similar results were noted for net income less family labour, except among households in treatment *pos* whose change in net income less family labour was negative. On average, net income less family labour among households applying various treatment increased by about 48%. The greatest increase was observed among farmers who applied *posmatfb* treatment (115%), followed by *posfb* (95%). On the other hand, we noted a decline in net income among households in the *pos* treatment (of 7%) and those in the control group (40%). The results on the percentage changes are not reported in Table 2 but are available upon request from the authors.

In line with our expectations, the total cost of purchasing pesticides reduced after the intervention across all the treatments. However, the reduction across the treatments did not differ significantly from the reduction reported by the control group. On average, expenditure on pesticides decreased by about 45% across all the treatments and by about 60% for the control. Similarly, when we isolated the cost of purchasing pesticides for management of fruit flies, the change in pesticide expenditure accrued by each of the treatments between the two survey periods was generally comparable to that for the control group households. The results differentiating pesticide expenditure on fruit fly control are also not reported in Table 2 but available from the authors upon request. The ratio of pesticide cost to mango revenue was also comparable between respective IPM treatment and control households.

Mango losses due to fruit fly damages were significantly lower across all the IPM groups compared to the control group. On

Table 2
Average change in outcome measures between the follow-up and baseline surveys.

	Posbiop (*n* = *78*) [*1*]	*Posfb* (*n* = *92*) [*2*]	*Posfbbiop* (*n* = *67*) [*3*]	*Posmat* (*n* = *112*) [*4*]	*Posmatbiop* (*n* = *106*) [*5*]	*Posmatbiopfb* (*n* = *68*) [*6*]	*Posmatfb* (*n* = *89*) [*7*]	*Pos* (*n* = *82*) [*8*]	*Control* (*n* = *134*) [*9*]
Mango revenue less cost of input cost (Ksh/acre)	51,273**	83,744***	76,593***	52,331***	59,893***	62,461***	76,635***	42,393***	14,814
	(60,677)	(173,696)	(107,422)	(83,272)	(60,936)	(100,194)	(185,134)	(92,894)	(46,356)
Change in mango revenue less cost of input cost (Ksh/acre)	6516	72,522***	38,490	28,729	32,277	42,811	70,876***	15,062	−5158
	(87,266)	(244,302)	(139,708)	(120,114)	(75,261)	(149,151)	(258,699)	(12,471)	(63,128)
Net income less family labour (Ksh/acre)	61,163**	95,786***	85,985***	65,650***	68,987***	71,091***	85,244***	57,837***	25,260
	(63,986)	(174,223)	(110,109)	(84,845)	(60,180)	(100,890)	(185,863)	(85,272)	(46,182)
Change in net income less family labour (Ksh/acre)	−1552	61,901***	30,462	15,013	23,514	37,896	62,407***	−4308	−12,652
	(89,776)	(247,369)	(143,108)	(122,603)	(76,744)	(151,404)	(261,613)	(113,111)	(63,478)
Total cost of pesticides (Ksh/acre)	4202	4417**	4671***	4727***	3100	4110	4205*	4514***	2643
	(4524)	(4843)	(8090)	(6189)	(3783)	(4624)	(5217)	(5616)	(4079)
Change in total cost of pesticides (Ksh/acre)	−3169	−1748	−2147	−2773	−1905	−2873	−2052	−2826	−2731
	(4809)	(5711)	(10,925)	(7319)	(4615)	(5518)	(6980)	(7453)	(5689)
Ratio of pesticide cost to mango revenue	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	(0.3)	(0.8)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.4)	(0.3)
Change in ratio of pesticide cost to mango revenue	−0.1	−0.2	−0.1	0.0	−0.1	−0.1	−0.1	−0.1	−0.1
	(0.4)	(1.2)	(0.3)	(0.3)	(0.2)	(0.2)	(0.3)	(0.6)	(0.4)
Mango damaged by fruit fly (percent of total production)	17.3***	16.1***	19.9***	17.0***	17.1***	15.1***	13.3***	22.2***	42.3
	(15.1)	(15.9)	(18.6)	(16.7)	(16.5)	(13.7)	(14.7)	(15.6)	(16.7)
Change mango damaged by fruit fly (percent of total production)	−17.0***	−18.5***	−25.1***	−18.8***	−22.7***	−16.8***	−17.7***	−14.3***	11.6
	(19.3)	(18.8)	(20.5)	(20.1)	(17.0)	(15.5)	(16.2)	(16.8)	(23.8)

Note: Standard deviation in parenthesis; The tests for the equality of means are the bonferroni-adjusted significance of the difference between individual treatments (columns [1] through [8]) and the Control group (column [9]). The abbreviations for the IPM interventions are as follows: ***P*** = parasitoids release; ***os*** = orchard sanitation; ***fb*** = food bait; ***biop*** = biopesticides; ***mat*** = male annihilation technique. *p < 0.1, **p < 0.05, ***p < 0.01. The exchange rate at the time of the survey was approximately 86 Kenya shilling ((Ksh)/US$).
Source: author's household survey

average, treatment households registered between 17% and 25% reduction in mango losses due to fruit fly infestation between the two survey periods, compared to the 12% increase in losses, reported by the households in the control group.

3.2. Empirical results and discussion

Table 3 reports the estimates derived using the difference-in-difference estimator for the impact of IPM. Prior to running the models, a test was conducted to detect the problem of multi-collinearity between the variables included in the analysis. The results depicted no strong correlation since the values of Variance Inflation Factor (VIF) were by far less than 10. The models were estimated using robust standards errors due to possible presence of heteroskedasticity. Each column of Table 3 represents different outcome measures, starting with the model for net mango revenue (column (1)). Columns (2), (3), (4) and (5) present estimated coefficients for net income less family labour, total cost of pesticides, ratio of pesticide cost to mango revenue and proportion of mango rejection due to fruit fly infestation respectively.

Focussing on the difference-in-difference estimates, for some treatments, we see that net income increased between the two-survey rounds compared with the control group, although overall the level of net revenue did not change significantly. The change in net income is higher for mango producers who applied any of the following six combinations: *posfb*, *posfbbiop*, *posmat*, *posmatbiop*, *posmatbiopfb and posmatfb* (column (1)) as shown by the coefficient of the interaction between specific treatment and time dummies. No significant improvement in net income was generated by *posbiop* and *pos* relative to the improvement exhibited by control group in the same period. Treatment *posfb* seems to have the highest impact of about KSh.72, 097 compared to the control group, while treatment *posmat* showed the least impact of about KSh. 28, 789 compared to the control group. Moreover, in the second round of survey, the level of net income was significantly higher for all the treatments in comparison to the control group except *posmatfb* and *pos* as shown by individual treatment coefficients.

With respect to net income less family labour, column (2) of Table 3, we observed a consistent impact of the fruit fly IPM strategy. However, in contrast to the constant estimate of the net income, the coefficient on time dummy was negative and significant indicating that overall net income less family labour declined over the two survey periods. The coefficients on the interaction of all the IPM combinations and time dummy (except for *posbiop* and *pos)* included in the model were positive, suggesting positive impact of the IPM combinations on net income less family labour as compared to the control group.

The estimates for the total cost of pesticides given in column (3) of Table 3 show a significant decrease in use of pesticides (KSh. 2630 per acre), independent of IPM strategy, between the two survey rounds. With regard to specific IPM treatments, there was no impact on cost of pesticides in comparison with the control group. However, when we estimated similar model using the cost of pesticides used for control of fruit flies, treatments *posbiop*, *posmat*, *posmatbiopfb* and *posmatfb* depicted significant decrease compared to the control group, and unobserved heterogeneity across households. These estimation results are not given here but are available upon request from the authors. The results for the mentioned treatments agree with earlier studies, for instance Fernandez-Cornejo (1996), who assessed the impact of IPM for insect and diseases on pesticide use, yields, and farm profits among fresh tomato producers in USA, and found significant decrease on use of insecticides and pesticides among IPM adopters compared to non-adopters. Similarly, Miranda et al. (2005) found IPM to be the most efficient system for pesticide control in terms of yields and pesticides use to control leaf miners, fruit borers and natural enemies in tomato crops in Brazil. In contrast to our expectations however, the coefficients of the specific treatments, specifically *posbiop*, *posmat*, and *pos* implied that households who applied these treatments reported significantly higher cost of pesticides per acre than the control group. This assessment could be due to the fact chemical pesticides use was not differentiated into insecticide and fungicide in the above analysis. To manage powdery mildew and anthracnose, mango growers in the region routinely apply

Table 3
DiD models for mango fruit fly IPM strategy effects on income, pesticide expenditure and mango loss.

	Mango revenue less cost of input cost (Ksh/acre) (1)	Net income less family labour (Ksh/acre) (2)	Total cost of pesticides (Ksh/acre) (3)	Ratio of pesticide cost to mango revenue) (4)	Mango damaged by fruit fly (percent of total production) (5)
Follow up (θ)	−3825.05	−11,534.86**	−2632.85***	−0.13***	10.43***
	(5651.2)	(5627.0)	(476.6)	(0.04)	(1.94)
Posbiop1(β_1)	22,587.35***	23,946.15***	1618.10**	−0.02	−10.24***
	(8505.3)	(8939.1)	(739.5)	(0.06)	(2.42)
Posbiop*follow up (Γ_1)	9116.48	8521.64	−584.17	0.02	−27.45***
	(11,505.9)	(11,948.4)	(845.5)	(0.06)	(2.83)
Posfb (β_2)	23,488.02***	27,310.03***	1149.31	0.07	−10.72***
	(8542.2)	(9262.4)	(738.0)	(0.13)	(2.31)
Posfb*follow up (Γ_2)	72,097.30***	69,876.21***	901.22	−0.03	−29.29***
	(24,724.7)	(25,090.6)	(857.1)	(0.13)	(2.67)
Posfbbiop (β_3)	32,817.43**	33,311.75**	1772.82	−0.04	−4.46
	(13,547.6)	(14,141.1)	(1300.9)	(0.05)	(2.58)
Posfbbiop*follow up (Γ_3)	38,898.18**	39,318.38**	507.2	0.05	−35.48***
	(19,417.2)	(19,980.4)	(1476.1)	(0.05)	(3.00)
Posmat (β_4)	15,025.61*	21,503.28***	2111.94***	−0.04	−10.19***
	(7678.9)	(8042.1)	(814.5)	(0.04)	(2.32)
Posmat*follow up (Γ_4)	28,789.32**	23,912.34*	−111.01	0.08	−29.18***
	(12,163.0)	(12,462.7)	(934.2)	(0.05)	(2.65)
Posmatbiop (β_5)	17,582.81***	18,475.90***	−125.39	−0.07	−8.21***
	(6782.7)	(68,09.2)	(630.2)	(0.04)	(2.15)
Posmatbiop*follow up(Γ_5)	34,705.85***	33,949.37***	672.73	0.05	−32.90***
	(9780.7)	(9897.3)	(684.0)	(0.04)	(2.49)
Posmatbiopfb (β_6)	17,122.29**	14,800.7*	1341.06	−0.03	−12.43***
	(8193.7)	(8348.3)	(808.2)	(0.04)	(2.25)
Posmatbiopfb*follow up (Γ_6)	42,191.18**	45,723.61**	−306.8	0.02	−26.99***
	(17,953.6)	(18,183.1)	(896.9)	(0.05)	(2.66)
Posmatfb (β_7)	15,761.61	15,618.55	1088.06	−0.01	−14.28***
	(10194.2)	(10,444.1)	(744.9)	(0.05)	(2.28)
Posmatfb*follow up (Γ_7)	69,969.48**	70,312.20**	579.11	−0.01	−28.35***
	(27,682.2)	(27,860.5)	(902.0)	(0.05)	(2.58)
Pos (β_8)	13,659.88	23,620.08***	1700.07*	0.02	−8.68***
	(9368.0)	(7540.3)	(866.9)	(0.07)	(2.35)
Pos*follow up (Γ_8)	22,165.91	10,031.17	−215.8	0.02	−24.00***
	(15,533.8)	(14,281.6)	(968.3)	(0.07)	(2.85)
Head education	511.6	98.06	63.00**	0.004**	−0.13
	(637.0)	(642.9)	(30.4)	0.00	(0.09)
Household size	−1213.77	−680.09	89.72	0.01	−1.76***
	(2838.7)	(2859.4)	(154.8)	(0.01)	(0.35)
Non-agro business	6230.89	8121.05	924.17***	0.01	−0.05
	(8083.8)	(8058.3)	(351.2)	(0.02)	(0.81)
Land holding	−85.81	−199.73	35.15	0.003	−0.18**
	(620.0)	(622.1)	(41.2)	(0.002)	(0.07)
Mango experience	534.67	493.88	16.93	0.000	−0.31***
	(628.8)	(632.0)	(26.4)	(0.001)	(0.06)
Extension contact	20,539.54***	15,700.73***	−526.15**	−0.01	0.99
	(5606.5)	(5663.6)	(266.8)	(0.02)	(0.70)
Improved mango trees	217.77	218.83	25.02***	0.001***	0.08***
	(221.1)	(225.5)	(7.4)	(0.0004)	(0.0)
Constant	−20,420.24	6856.02	1300.48	−0.01	40.21***
	(29,304.6)	(29,885.6)	(1052.9)	(0.08)	(4.1)
Number of observations	1656	1656	1656	1646	1656
F	9.14***	8.88***	9.12***	4.75***	87.53***
R-squared	0.09	0.07	0.10	0.03	0.52

Note: Robust standard errors in parenthesis. *p < 0.10, **p < 0.05, ***p < 0.01. *Gender, head age, livestock, and distance to market* are included in the analysis but statistically insignificant in all specifications. The estimation also includes individual treatment variables as given in Table 3. Full regression results are available upon request *Source*: author's household survey

fungicides and depending on the season and variety of mango planted, application can increase or decrease within a given area and this may have influenced grower responses and the results obtained. Column (4) which presents the estimates for the ratio of pesticide cost to mango revenue followed a similar pattern as the expenditure on synthetic pesticides estimates. Regardless of the fruit fly IPM intervention, the ratio of the pesticide cost to mango revenue decreased. This could also be attributed to decrease in mango revenue as shown by the coefficient of time dummy in column (2).

In terms of mango damaged by fruit fly (column (5) of Table 3), we observed that in general, damage increased significantly between the two survey periods. However, coefficients for specific IPM treatments showed a significant decrease in comparison to the control group. On average, mango damage out of total production reduced by about 30% across all the treatment, with treatment *posfbbiop* reporting the highest decrease of about 37%, while treatment *pos* reported the least decrease of about 26%. Besides, the coefficients of the specific treatment dummies imply that, by the second round of survey, the level of mango loss due to fruit fly infestation was significantly lower for households that received IPM treatments in comparison to control group. Decrease in mango losses due to fruit fly as a result of IPM interventions has also been demonstrated in other related studies, such as Verghese et al. (2004) and Kibira et al. (2015) who carried out economic evaluation of IPM of oriental fruit fly in mango production in India and Kenya respectively. Verghese et al. (2004) found that the use of IPM package resulted in a considerable fruit fly supression at many levels of fly attack pressure, but net returns decreased after reaching a certain threshold.

Table 4 presents the estimated coefficients for the fixed effect specification as outlined in Eq. (2). Similarly to the DiD specification for net income, the results for the standard fixed effects estimation consistently suggest positive and significant relationship of IPM treatments that were significant in the previous estimation. However, the coefficients were somewhat smaller when we controlled for unobservable individual heterogeneity as shown in column (1) of Table 4. With regard to net income less family labour, controlling for unobservable time-invariant factors rendered some coefficients insignificant as shown in column (2) in comparison to the DiD estimators. However, the fixed effects estimates for treatments *posfb*, *posmatbiop*, and *posmatfb* exhibited positive and significant impact on net income in the same way as the DiD results. The results for mango damaged by fruit flies are similar to those of the DiD estimation when we controlled for household's observed and time-invariant characteristics as shown in column (5) of Table 4.

Table 3 also presents the estimated coefficients for the exogenous variables that are likely to influence the outcome measures of interest. Education of the household head exerted a positive and significant influence on expenditure on pesticides. Education enhances access to information and farm management skills, thus more educated heads were likely to have easy access and to apply more pesticides as compared to less educated ones. Household size exhibited a negative relationship to the proportion of mango damage as a result of fruit fly infestation. This could probably be attributed to availability of higher labour resources required in monitoring mango production to remove any pest-infected mango to prevent spread of such infestation and hence less mango damage due to efficient utilization of those resources. Pesticide expenditure showed a significant relationship with ownership of non-agro business. Specifically, access to a non-agricultural business was associated with increase in cost of pesticides of about KSh. 924 per acre. This relationship emphasizes the importance of income diversification, since off-farm business may provide the necessary capital for purchasing inputs especially among credit constrained rural communities. The size of land holding yielded a negative and

Table 4
Household fixed effects models for mango fruit fly IPM strategy effects on income, pesticide expenditure and mango loss.

	Mango revenue less cost of input cost (Ksh/acre) [1]	Net income less family labour (Ksh/acre) [2]	Total cost of pesticides (Ksh/acre) [3]	Ratio of pesticide cost to mango revenue) [4]	Mango damaged by fruit fly (percent of total production) [5]
Follow up (dummy)	−2452.4	−8671.3	−2592.4***	−0.12***	10.4***
	(5970.2)	(5963.0)	(495.8)	(0.04)	(2.1)
Posbiop*follow up (Γ_1)	6110.2	4006.9	−551.069	0.02	−27.0***
	(11,990.2)	(12,309.5)	(742.6)	(0.06)	(3.1)
Posfb*follow up (Γ_2)	71,091.9***	66,565.1***	720.465	(0.04)	−28.7***
	(24,014.2)	(24,313.5)	(775.5)	(0.13)	(2.9)
Posfbbiop*follow up (Γ_3)	36,452.0**	34,267.7	257.839	0.05	−35.1***
	(18,343.1)	(18,687.9)	(1457.7)	(0.05)	(3.2)
Posmat*follow up (Γ_4)	25,871.7**	18,075.1	−447.9	0.07	−28.8***
	(12,940.1)	(13,100.7)	(864.2)	(0.04)	(2.8)
Posmatbiop*follow up (Γ_5)	31,186.6***	27,858.9***	503.1	0.05	−32.9***
	(9984.7)	(10,028.2)	(671.3)	(0.04)	(2.7)
Posmatbiopfb*follow up (Γ_6)	35,592.8	35,813.7	−530.5	0.00	−26.1***
	(20,315.3)	(20,554.1)	(847.9)	(0.05)	(3.0)
Posmatfb*follow up (Γ_7)	65,559.5**	62,844.3**	250.3	(0.03)	−27.7***
	(27,915.0)	(28,184.8)	(900.4)	(0.05)	(2.8)
Pos*follow up(Γ_8)	22,608.6	8716.2	−242.6	0.02	−24.7***
	(15,887.3)	(13,374.1)	(960.0)	(0.07)	(2.9)
Gender	67,555.8	69,997.8	1133.3	0.00	−3.6
	(40,980.3)	(41,600.6)	(690.6)	(0.03)	(4.0)
Head age	−693.1	−619.6	64.3*	0.00	0.17
	(716.8)	(728.7)	(31.1)	(0.00)	(0.1)
Head education	1992.6	2185.2	127.9	0.00	−0.24
	(1289.3)	(1307.4)	(72.1)	(0.00)	(0.2)
Household size	−3124.5	−1725.9	15.7	(0.01)	−1.13
	(5386.7)	(5451.5)	(293.4)	(0.02)	(0.8)
Land holding	968.878	1223.2	68.6	0.00	−0.014
	(1018.6)	(984.3)	(67.4)	(0.00)	(0.2)
Livestock	6244.1	7584.1*	48.8	0.01	−1.01*
	(3958.9)	(3912.9)	(181.7)	(0.02)	(0.4)
Extension contact	17,133.7**	15,357.7**	626.8	0.01	−1.49
	(7559.2)	(7727.3)	(446.9)	(0.02)	(1.1)
Improved mango trees	169.4	201.1	16.0	0.00	0.12**
	(323.7)	(328.6)	(9.9)	0.00	(0.1)
Constant	−51,872.9	−54,487.6	−2894.9	0.153	19.259
	(73,035.1)	(73,672.1)	(2353.4)	(0.2)	(10.3)
Number of observations	1656	1656	1656	1646	1656
F	3.7***	2.9***	9.8***	4.9***	50.9***
R-squared	0.089	0.071	0.139	0.044	0.49

Note: Robust standard errors in parenthesis; *p < 0.1, **p < 0.05, ***p < 0.01; Control group is the reference category used for the tests of the average differences with the given treatments.
Source: author's household survey.

significant association with share of mango damaged by fruit flies. Households with large farms are likely to engage in commercial mango production, and employ skilled farm personnel and hence less fruit damages. Similarly longer period of mango farming (mango experience) may imply enhanced fruit flies control skills and hence the negative and significant relationship with the share of mango losses due to fruit fly. Access to extension services exerted a positive and significant influence on net income and opposite relationship with expenditure of pesticides. This is plausible as extension contact may provide important information on management of mango production including management of pests using lower levels of pesticides. Extension services are considered essential channels for disseminating production and marketing information especially among rural households.

In conclusion, this paper is an important contribution to the literature on the impact of fruit fly IPM strategy on mango production and thus livelihood of mango producers. Diverting from previous studies that have so far used cross-sectional data, and looked at IPM strategy in general, this study employed a panel data set of two waves of survey using a quasi-experimental research design. Further, the study applied methods that allowed us to control for the non-random nature of IPM strategy adoption in order to estimate the impact of different combinations of IPM components for mango fruit fly control on net income, pesticide expenditure and mango losses due to fruit fly infestation.

Taken together, the results point to the importance of IPM strategy as we observed, among households applying various combinations of IPM components as treatments, a 48% increase in mango net income less family labour. Treatments *posmatfb* and *posfb* seem to have had the highest profit margin while *pos* treatment and the control group reported a decrease in mango profits. Qualitative information gathered from the field revealed difficulties among smallholders in applying biopesticides especially soil drench, which could explain the low score for the IPM packages that contained this component. Descriptive statistics further showed that expenditure on pesticides decreased by an average of 45% across all the treatments, although the difference was not significantly different from the control group that also reported a decrease between the two survey periods. With regard to mango losses due to fruit fly infestation, a notable reduction was found across all the IPM treatments recording an average of 17%.

To quantify the impact of IPM strategies on mango economic indicators, we employed in this study difference-in-difference method, and checked its robustness with fixed effects regression. The results showed positive and significant increase in net income for treatments *posfb*, *posfbbiop*, *posmat*, *posmatbiop*, *posmatbiopfb* and *posmatfb* compared to the control group. The results were robust as they were similar to those obtained when we controlled for exogenous variables, as well as when we controlled for household unobservable heterogeneity. The highest impact was reported from treatment *posfb*, while treatment *posmat* showed the least impact. With regard to expenditure on pesticides, the results indicated that IPM adopting farmers were still using other pesticides in general (but mostly fungicides) but fairly reducing those for controlling fruit flies. With respect to mango losses, there was a significant decrease across households adopting different treatments, with the largest decrease reported by farmers combining parasitoid release, food bait and biopesticide (*posfbbiop*).

These results provide key highlights for the African fruit fly programme in identifying the combination of IPM components with the highest impact for scaling up among other communities. Clearly, a combination of affordable and easy to apply (and maintain) IPM strategies, for instance, biological control (*parasitoids*), cultural control *(orchard sanitation)* and minimal (and affordable) baiting techniques using food bait could yield significant impact on mango fruit fly control. A private sector company, Kenya Biologics Ltd (www.kenyabiologics.com) jointly with ICIPE is in the process of establishing a local food bait production facility for fruit fly management across Africa. The food bait should become available in the not distant future at relatively cheaper price than imported products for horticultural growers in the continent. The biopesticide used in this study is produced by Real IPM Ltd, Kenya and already available commercially for use across Africa as indicated earlier. Methyl eugnol is also commercially available across different outlets in Africa. Several government agencies are also engaged in parasitoid releases targeted at *B. dorsalis* in various African countries (Ekesi et al., 2015). The Augmentorium can be fabricated locally by smallholder farmers for orchard sanitation and parasitoid conservation.

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