# Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya

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## Abstract

*This paper evaluated the economic benefits of managing mango-infesting fruit flies in Embu County, Kenya using an integrated pest management (IPM) package composed of male annihilation technique (MAT), protein bait spray, releases of exotic parasitoid* Fopius arisanus *and the use of augmentorium. The difference-in-difference (DiD) method was used to assess the impact of the mango IPM on the magnitude of mango rejection and insecticide expenditure and net income. The study revealed that, on average, mango IPM participants had an approximately 54.5% reduction in the magnitude of mango rejection; spent 46.3% less on insecticide per acre and received approximately 22.4% more net income than the non-participants. This implies a high economic benefit from the application of the fruit fly IPM technology, and mango farmers would profit significantly if the intervention was expanded to provide wide coverage of other mango-growing areas in Kenya.*

**Key words**: IPM, mango, economic impact assessment, difference-in-difference, Kenya

## 1. Introduction

### 1.1 Background

Mango (*Mangifera indica* L.) is an important food and cash crop and plays an important role in the agricultural development in many countries in sub-Saharan Africa (Lux *et al*. 2003). It is the third most important fruit in Kenya in terms of area and total production (Food and Agriculture Organization [FAO] 2009b). In the country, the crop is grown mainly by smallholder farmers as a source of food to meet their dietary (vitamins and mineral) needs and as a major source of household income. In 2010, the cumulative area under mango production was 34 371 hectares, with a total production of 537 315 metric tons worth US$ 97.6 million (Horticultural Crops Developing Authority [HCDA] 2010). The fruit crop also accounted for 26% of the major fresh fruit trading in the export market. The main mango-producing areas in Kenya are the Coast, Eastern, Nyanza, Rift Valley and Central regions. In 2010, about 10 035 hectares were under mango production in the Eastern region, with a total production of 93 958 metric tons (HCDA 2010). In the Eastern region, Embu County ranks third in mango production. The area under mango production and total production in Embu County rose from 3 553 hectares and 23 488 metric tons respectively in 2010 to 3 744 hectares and 42 995 metric tonnes in 2012 (HCDA 2013). As an export crop, mango earns the country foreign exchange, and it acts as a source of food and household income for resource-poor farmers. In 2010, mangoes earned Kenya US$ 70 million in the domestic market and US$ 10.1 million in export earnings (HCDA, 2010). The volume of mango produced has increased over the years, from below 250 000 metric tons in 2003 to over 750 000 metric tons in 2012 (USAID-KHCP 2015). However, the country is yet to achieve its potential of about 2.8 million metric tons (HCDA 2013).

### 1.2 Economic importance of fruit fly in mango production and marketing

The production and marketing of mango are affected by a variety of factors, of which pests and diseases are regarded to be the major constraints. Among the insect pests, fruit flies are known to be the most notorious (Lux *et al.* 2003; Ekesi & Billah 2007; Ekesi *et al*. 2009; Isabirye *et al*. 2015). In Africa, the economically important species belong to the genera *Bactrocera*, *Ceratitis*, *Dacus* and *Trirhithrum* (De Meyer *et al.* 2014). The genera *Ceratitis*, *Dacus* and *Trirhithrum* are known to be indigenous to Africa, and the *Bactrocera* are native to Asia. Female fruit flies that lay eggs under the skin of the fruits cause direct losses. The eggs hatch into larvae that feed on the decaying flesh of the crop. Infested fruit rot quickly and become inedible or drop to the ground. Beside the direct damage to fruit, indirect losses are associated with quarantine restrictions, because infestation and sometimes the mere presence of the flies in a particular country could restrict the trade and export of fruit to markets abroad (Bissdorf & Weber 2005). Tephritid fruit flies cause direct damage to important export crops such as mango, avocado and cucurbits, leading to losses of 40% to 80%, depending on locality, variety and season (FAO, 2009a).

In Eastern and Southern Africa, five indigenous fruit fly species (*Ceratitis cosyra*, *C. fasciventris*, *C. rosa*, *C. anonae* and *C. capitata*) attack mango (Ekesi & Billah, 2007). Several surveys across the region showed a 30% to 70% yield loss in mango due to these native fruit flies, depending on the locality, variety and season (Lux *et al*. 2003; Ekesi *et al*. 2009). However, since the invasion by *Bactrocera invadens* in East Africa in 2003, damage to mango has increased to over 80% (Ekesi *et al*. 2009; 2010; Goergen *et al*. 2011). The rapid spread and devastating impact of *B. invadens* is a serious concern to the mango industry in Kenya and Africa at large. The export of host fruit species of *B. invadens*, such as mangos from Uganda, Tanzania and Kenya, are already banned by the Seychelles, Mauritius and South Africa. Trade in several horticultural produce between Africa and the United States of America (USA) has been severely hampered by a US Federal Order banning the importation of several cultivated fruit and vegetables from African countries where *B. invadens* has been reported (United States Department of Agriculture, Animal and Plant Health Inspection Service [USDA-APHIS] 2008).

### 1.3 Integrated management of mango fruit flies

In Kenya, the commonly used method of controlling fruit flies by many farmers is intensive insecticide cover sprays. This is not only highly costly for the growers, but also damaging to the health of the farmer workers, the environment and non-target beneficial organisms. Early mango harvesting is also practised to evade fruit fly attack, but this is not effective for certain fruit fly species, such as *B. invadens and C. cosyra*, which can infest both the immature and mature green mangoes (Ekesi & Billah 2007). Due to the economic importance of mango fruit fly, efforts have been made by the International Centre of Insect Physiology and Ecology (*icipe*), in collaboration with national (the Kenya Plant Health Inspectorate Service (KEPHIS), the Kenya Agricultural Research Institute (KARI) and the Ministry of Agriculture, Kenya) and international partners (University of Bremen, Max Planck Institute of Chemical Ecology, USDA) to develop an integrated pest management (IPM) package to address the fruit fly problem in Africa. The fruit fly IPM package is aimed at enhancing sustainable mango production and marketing by reducing economic losses at the farm level and insecticide usage, and increasing the supply of quality mangoes to meet the requirements of domestic and export markets and in an effort to raise the profit margins of the producers, thus improving their livelihood. By definition, IPM is a diverse mix of approaches to manage pests and keep them below damaging levels, using control options that range from cultural practices to chemical pesticides (Sorby *et al*. 2003).

The *icipe*-developed fruit fly IPM package is a combination of various fruit fly management techniques; these include the use of the male annihilation technique (MAT), the application of protein bait spray, the use of fungus-based biopesticide (although not included in these particular trials), releases of exotic parasitoids, and orchard sanitation that encompasses the use of augmentorium (Verghese *et al*. 2006; Ekesi *et al*. 2010). The MAT involves the use of carriers (fruit fly traps) containing male lure (methyl eugenol) combined with an insecticide, which are distributed at regular intervals over a wide area in the mango orchard to reduce the male population of fruit flies to a low level so that mating does not occur or is extremely reduced (Allwood *et al*. 2002; Ekesi & Billah 2007; Ekesi *et al*. 2010). The protein-baiting technique is based on the use of proteinaceous food baits combined with an insecticide, applied to localised spots of one square metre in the canopy of each tree in the orchard when fruits are 1.3 cm in size. Spraying is done weekly until the very end of harvest (Ekesi & Billah 2007). The proteinaceous substance attracts the adult fruit flies, mainly females, from a distance to the bait spray droplets. The fruit flies ingest the bait, along with a toxic dose of insecticide, killing them before they infest the fruit (Prokopy *et al*. 2003; Ekesi *et al*. 2010). Biopesticides are applied to the soil within the dripline of the canopy to kill the soil-dwelling pupariating larvae and puparia. The egg parasitoid. *Fopius arisanus,* was released in the Nthagaiya and Karurumo sub-locations in Embu County during the implementation of the IPM trials. The females of *Fopius arisanus* destroy fruit flies by laying eggs on fruit flies' eggs in previously damaged mango fruits. The parasitoid eggs hatch to produce larvae that grow by feeding on the internal tissue of the flies' larvae, ultimately killing the fruit flies (Hanna *et al*. 2008; Ekesi *et al*. 2010).

Orchard sanitation is the cultural method used to prevent fruit fly build up. The method involves the collection of infested fruit found on the trees or fallen on the ground and depositing them in an augmentorium (Ekesi *et al*. 2010). An augmentorium is a tent-like screen structure designed to sequester fruit flies emerging from infested fruits, but at the same time allows the escape of parasitoid wasps via a screen on the top so that they can re-enter the field, thus conserving the natural enemies of fruit flies (Ekesi & Billah 2007). A household survey conducted among mango farmers in Kenya revealed that 58.5% of the sampled mango farmers adopted at least one component of the fruit fly IPM package (Korir *et al*. 2015). The empirical results of the study highlighted the importance of education of the household head in the adoption of fruit fly IPM strategies in Embu County, situated in eastern Kenya. Furthermore, farm management practices, including record keeping, the use of protective clothing during spraying and participation in IPM training at demonstration sites, were found to have a positive influence on the intensity of the adoption of the fruit fly IPM packages. In addition, the number of mature mango trees could be associated with high adoption of the IPM strategies (Korir *et al*. 2015). A lack of training and technical support provided to mango farmers has been highlighted in other studies as a contribution to low adoption of IPM technologies in developing countries (Parsa *et al*. 2014). Low farm productivity may also hamper IPM adoption efforts, as well as poor dissemination of the IPM research information to farmers (Morse & Buhler, 1997; Parsa *et al*. 2014).

The purpose of this study was to assess the economic effect of the *icipe* fruit fly IPM strategies in a smallholder setting to determine the impact of the intervention on marketable mango produce losses, insecticide expenditure and net income accrued from mango farming.

## 2. Materials and methods

### 2.1 Study area

This study was conducted in Embu East District (presently Runyenjes sub-county) in Embu County. The sub-county lies between 1 000 and 2 070 metres above sea level and has a total area of 253.4 square kilometres, of which 177.3 square kilometres is arable land. According to the 2009 population and housing census, the study area has a total population of 115 128 persons with an average family size of six. The average farm size in the sub-county is 1.2 hectares, and farm families are estimated at 30 000, out of which 3 030 are mango growers (Ministry of Agriculture [MoA] 2010). The area is characterised by three main agro-ecological zones, namely Lower Highlands, Upper Midland and Lower Midland. Rainfall is bimodal, with the long rainy season occurring in March/June and the short rainy season in October/December, with an annual rainfall of 800 mm to 1 500 mm. The soils are generally fertile, well-drained, extremely deep, dark reddish brown to dark brown and friable clay with humic top oils – mainly humic nitisols and andosols (Jaetzold *et al*. 2006). Agricultural production in this sub-county is mainly subsistence and rain fed. Mango is considered one of the most important cash crops in the area.

### 2.2 Data collection and sampling

Data were collected from two purposively selected sites: (1) the intervention area (sub-locations where farmers participated in fruit fly IPM) and (2) the control area (non-participating fruit fly IPM farmers). The fruit fly IPM intervention participants and non-participants were drawn at random from lists obtained from the Runyenjes sub-county agricultural office. A total of 276 mango farmers (138 farmers for each group) were sampled and a structured questionnaire was administered to each on their farms by trained enumerators. Data were collected in two scenarios: 'before' and 'after' the fruit fly IPM package intervention. A baseline study was conducted in 2011, before the intervention, to establish the existing situation as a function of variables defined for the IPM package. A follow-up survey was then conducted after the intervention in 2012, when 257 mango farmers were re-interviewed – 121 participants and 136 non-participants. The number of mango farmers interviewed during the follow-up survey was lower than baseline due to the unavailability of household members even after repeated attempts, the exclusion of those with obvious data errors, and refusal by some respondents. The baseline and the follow-up surveys measured the same variables, only at different times.

### 2.3 Data analysis

This study employed a difference-in-difference (DiD) estimation model to evaluate the economic impact of the fruit fly IPM package on the magnitude of mango produce rejection due to fruit fly infestation, insecticide expenditure and net income. Two years of panel data (2011 and 2012) were used for this purpose. DiD essentially compares the participants (with) and non-participants (without) before and after an intervention by using a pre-intervention baseline survey and post-intervention data (Khandker *et al*. 2010). Regression analysis was used to estimate the DiD in determining the impact of the mango IPM intervention. The analysis was done on two levels: (1) with the basic assumption that other socio-economic variables do not change with time (unconditional), and (2) that these variables vary across the years and may affect the outcome of interest (conditional). The model to estimate the effect of fruit fly IPM (Khandker *et al*. 2010) is expressed as:

$$Y_i = \alpha + \beta T_i + \gamma t_i + \delta T_i * t_i + \varepsilon_i \quad (1)$$

$$Y_i = \alpha + \beta T_i + \gamma t_i + \delta T_i * t_i + \boldsymbol{\lambda}_i \boldsymbol{X}_i + \varepsilon_i \quad (2)$$

where $Y_i$ is outcome of interest, in our case magnitude of mango rejection, insecticide expenditure and net income from mango production; $T_i$ is the treatment dummy variable; $t_i$ is the time dummy; $X_i$ is the set of socio-economic variables that may affect $Y$; the coefficient of interaction of $T_i * t_i$ ($\delta$) gives the estimate of the impact of mango IPM on outcome $Y$; $\beta$ accounts for average permanent differences between the treatment and control groups; $\gamma$ is the time trend common to both the treatment and control groups; $\boldsymbol{\lambda}$ is a vector of coefficient of the exogenous variables $\boldsymbol{X}_i$; and $\varepsilon$ is the error term. The magnitude of mango rejection was determined as a percentage of the quantity of mango not sold or consumed by the participants and non-participants in fruit fly IPM due to damage caused by the mango fruit fly. The insecticide expenditure considered was the pesticide cost incurred per acre by the mango farmers in controlling mango fruit flies. Net income in this study refers to total revenue received from mango less the variable production costs incurred per acre by mango farmers before and after the intervention. Among the independent variables, the socio-economic variables were: age, land under mango, mature mango trees, years in school, experience in mango growing, agricultural extension contact, distance to market, total livestock units, intercrops in mango plot, credit acquisition for mango production, dependency ratio, and price of mango. Socio-economic data were analysed using descriptive statistics with STATA software. Before regression analysis, preliminary tests were done on the data and appropriate corrections were employed to control for estimation bias. These tests were normality, linearity, multicollinearity, heteroscedasticity and autocorrelation. For the dependent variables, magnitude of mango rejection and insecticide expenditure and natural log transformation were used to correct deviation from normality. To correct for endogeneity in estimating the effect of the intervention on net income, the Two-stage Least Square (2SLS) method was used. The iterative Prais-Winsten method was used to adjust for autocorrelation.

Using the DiD, the impact of the fruit fly IPM intervention was also estimated by calculating the mean difference in magnitude of mango rejection, insecticide expenditure and net income between IPM participants and IPM non-participants after the intervention minus the mean difference in outcomes between the two groups before intervention. Table 1 displays the format, showing the groups being compared in the columns and the time periods in the rows. The DiD in the table is the difference-in-difference estimate (Ahmed *et al*. 2009).

**Table 1: DiD estimate of average mango IPM effect**

| Survey | Mango IPM participants (I) | Mango IPM non-participants (C) | Difference across groups |
|---|---|---|---|
| Follow up | $I_1$ | $C_1$ | $I_1 - C_1$ |
| Baseline | $I_0$ | $C_0$ | $I_0 - C_0$ |
| Difference across time | $I_1 - I_0$ | $C_1 - C_0$ | $DiD = [I_1 - C_1] - [I_0 - C_0]$ |

Source: Ahmed *et al*. (2009)

## 3. Results and discussion

In estimating the impact of fruit fly IPM on the magnitude of mango rejection, the findings in Table 2 show a negative and statistically significant ($p < 0.01$) coefficient of both an unconditional and conditional treatment effect of the intervention (interaction $T_i x t_i$), implying that a reduction in the magnitude of mango rejection, even in the presence of other factors, may affect mango rejection. This indicates that farmers who participated in the fruit fly IPM intervention experienced a higher reduction in magnitude of mango rejection than the non-participants. The result also showed a significant ($p < 0.1$) negative correlation between agricultural extension services and magnitude of mango rejection. A one-unit increase in the number of times households sought agricultural extension services would likely result in a reduction of approximately 9.4% in the magnitude of mango rejection. This seems to suggest that efforts by mango farmers in seeking agricultural extension services equipped them with knowledge of fruit fly control and that they were well updated on new pest management techniques. The other factors were not significantly correlated with magnitude of mango rejection.

**Table 2: Impact of Mango IPM on magnitude of mango rejection**

| Model | Unconditional | | Conditional | |
|---|---|---|---|---|
| | Coefficient | t-ratio | Coefficient | t-ratio |
| HHTYPE $T_i$ | -0.248 | -2.70*** | -0.186 | -1.80* |
| Befor_After $t_i$ | -0.330 | -4.90*** | -0.331 | -4.90*** |
| Interaction$T_i$ x$t_i$ | -1.152 | -10.95*** | -1.146 | -10.83*** |
| Distance to market | | | 0.006 | 0.26 |
| Agriculture extension | | | -0.094 | -1.91* |
| Years in school | | | -0.002 | -0.21 |
| Experience in mango growing | | | -0.005 | -0.60 |
| Mature mango trees | | | -0.0003 | -1.27 |
| Constant term | 3.093 | 56.21 | 3.144 | 23.90 |
| $R^2$ | 0.7257 | | 0.7315 | |
| F | 1237.6*** | | 572.43*** | |

Dependent variable: ln magnitude of mango rejection; *** Significant at $p < 0.01$; * Significant at $p < 0.1$
Source: Field survey data

The mean differences in mango rejection between mango IPM participants and non-participants across the two time periods in Table 3, the DiD estimate, was negative (-12). The DiD estimate indicates that, on average, mango IPM participants experienced a reduction of approximately 54.5% in magnitude of mango rejection compared to non-participants (Table 3). The high reduction in magnitude of mango rejection for participants could be attributed to reduced fruit fly infestation. According to Verghese *et al*. (2006), a pre-harvest mango fruit fly IPM package consisting of a combination of male annihilation technique (MAT) (using methyl eugenol as a lure) and sanitation reduces *Bactrocera dorsalis* infestation to 5.00% from an infestation ranging from 17% to 66% in control mango orchards. Interviews with farmers in the study area revealed that one trap could capture more than 2 000 fruit flies per week. Traps in conjunction with bait sprays, which mainly reduce the female fruit fly population, the parasitoid and the use of augmentorium, led to reduced infestation and consequently a greater reduction in the magnitude of mango rejection for the participants than for the non-participants. This may lead to an increase in the quantity of fruit available for consumption and marketing. The results agree with findings by Vayssieres *et al*. (2009), who found that the use of GF-120 bait sprays reduced mango fruit fly infestation by 81% to 89% in Benin. This result is also consistent with that of Vargas *et al*. (2015), who reported that the use of the various mango fruit fly IPM components in combination lead to a reduction in fruit fly infestation by between 77% and 100%.

**Table 3: DiD estimate of average mango fruit fly IPM effect on the outcomes**

| Outcome | DiD estimate | Percentage change (%) |
|---|---|---|
| Magnitude of mango rejection | -12 | 54.5 |
| Insecticide expenditure | -377 | 46.3 |
| Net income (Kshs) from mango farming | 2,051 | 22.4 |

Source: Field survey data

Table 4 summarises the impact of mango IPM on insecticide expenditure. As indicated by the negative and statistically significant coefficient in both instances, the fruit fly IPM intervention reduced insecticide expenditure for the participants. The application of mango IPM techniques reduced insecticide expenditure by 46.3% (Table 3). This can be attributed to bait sprays applied to localised spots in the canopy of each mango tree, targeting the lower surface of the leaves to enhance the persistence of bait activity. This weekly insecticide spot spraying (one metre square) that commences at the onset of fruit maturity before mango harvest, as explained by Prokopy *et al*. (2003) and Ekesi *et al*. (2010), could have led to reduced spraying by the fruit fly IPM participants and thus reduced insecticide expenditure. This contrasts with the blanket conventional insecticide spraying employed by non-participants. The results are consistent with the findings of Jankowski *et al*. (2007), who found that the adoption of biological control agents by cabbage farmers in Kenya and Tanzania reduced pesticide usage by 34%. The results are also in accordance with those of Baral *et al*. (2006), who observed that adoption of IPM reduces insecticide expenditure by 52.6%.

**Table 4: Impact of mango IPM on insecticide expenditure**

| Model | Unconditional | | Conditional | |
|---|---|---|---|---|
| | Coefficient | t-ratio | Coefficient | t-ratio |
| HHTYPE $T_i$ | 1.635 | 5.68*** | 1.599 | 5.44*** |
| Befor_After $t_i$ | -0.063 | -0.25 | -0.074 | -0.29 |
| Interaction$T_i$ x$t_i$ | -1.190 | -3.97*** | -1.223 | -4.15*** |
| Years in school | | | 0.018 | 0.57 |
| Age of household head | | | 0.010 | 0.95 |
| Agriculture extension | | | -0.114 | -1.23 |
| Credit | | | 0.061 | 0.11 |
| Total livestock units | | | 0.034 | 0.79 |
| Experience in mango growing | | | 0.002 | 0.13 |
| Dependency ratio | | | -0.246 | -1.24 |
| Constant term | 4.751 | 17.81 | 4.118 | 5.05 |
| $R^2$ | 0.3386 | | 0.3469 | |
| F | 1017.04*** | | 420.17*** | |
| Dependent variable: ln insecticide expenditure; *** Significant at $p < 0.01$ | | | | |

Source: Field survey data

The results in relation to the effects of fruit fly IPM on net income are summarised and presented in Table 5. The positive and statistically significant coefficient clearly implies that, even in the presence of the other factors that may affect net income, farmers participating in the mango IPM intervention received more net income than the non-participants. On average, the participants received approximately 22.4% more net income than the non-participants (Table 3). The increase in net income could be explained by the fact that reduced fruit fly infestation led to increased marketable volume due to the improved quality of mango that fetched higher prices. At the same time, reduced insecticide expenditure lowers total production costs, thus most likely increasing the net income. These results are in agreement with Cuyno *et al*. (2001), who found that the adoption of IPM improves the economic benefits of onion farmers by between 231 and 305 pesos per person per cropping season and reduces pesticides use by between 25% to 65% in the Philippines. In addition, Isoto *et al*. (2008), while assessing the effect of integrated pest management (IPM) on net coffee revenue in Uganda, found that IPM adopters earned 118% higher coffee revenues compared to conventional farmers.

**Table 5: Impact of Mango IPM on net income from mango production**

| Model | Unconditional | | Conditional | |
|---|---|---|---|---|
| | Coefficient | t-ratio | Coefficient | t-ratio |
| HHTYPE $T_i$ | 7 773.17 | 6.32*** | -10 525.525 | -1.40 |
| Befor_After $t_i$ | 3 245.765 | 4.86*** | 697.081 | 0.31 |
| Interaction$T_i$ x$t_i$ | 2 864.225 | 2.15** | 5 928.902 | 1.80* |
| Price of mango | | | 3 389.024 | 2.24** |
| Years in school | | | 195.695 | 0.96 |
| Agriculture extension | | | -1 811.070 | -1.31 |
| ln land under mango | | | -2 089.812 | -0.71 |
| Intercrop count | | | 13.803 | 0.02 |
| Credit | | | -1 050.390 | -0.26 |
| Distance to market | | | -152.019 | -0.69 |
| Experience in mango growing | | | -128.620 | -0.65 |
| Constant Term | -34.128 | -0.05 | -15 557.630 | -2.33 |
| $R^2$ | 0.1786 | | - | |
| F | 44.14*** | | | |
| Wald chi$^2$(10) | - | | 59.67*** | |
| Dependent variable: Net income per acre; *** Significant at $p < 0.01$; ** Significant at $p < 0.05$; *Significant at $p < 0.1$ | | | | |

Source: Field survey data

## 4. Conclusion

The aim of this study was to assess the economic effect of fruit fly integrated pest management strategies among smallholder mango producers in Kenya, using a case study of Embu County. This paper is a unique contribution to the literature on the impact of fruit fly IPM technologies on mango production, and thus on the livelihood of mango producers in Kenya and in other mango-producing countries in sub-Saharan Africa. Besides using panel data and exploiting a method that accounts for the non-random nature of the adoption of IPM technologies, this study contributes to the literature by investigating the effects of the technologies on the magnitude of mango losses due to fruit fly infestation, expenditure on pesticides and net income.

The results reveal that there were significant differences in the levels of magnitude of mango rejection, insecticide expenditure for the control of fruit fly and net income from mango production between participants in fruit fly IPM intervention and non-participants. It is evident from our analysis that IPM for fruit fly management in mango generates substantial economic benefits for mango farmers in Embu County. The mango IPM intervention reduced mango rejections by 54.5%, insecticide expenditure by 46.3% and increased net income by 22.4%.

Our study emphasises that this technology is an authentic tool in poverty alleviation, considering the vital role mango plays in Kenya. IPM strategies therefore should be scaled up to other mango-producing regions in the country and in sub-Saharan Africa, where fruit flies are widespread. Since this was a pilot study, the government and development partners in the agricultural sector can improve the adoption of the strategies by integrating IPM training into agricultural interventions. Future research addressing measures of household welfare, such as food security, poverty and gender, should be considered to help better understand the long-term impacts of the IPM strategies on mango fruit fly control among smallholders in sub-Saharan Africa. In addition, while this study does not elucidate the impact of different IPM components or combinations, further research using different combinations of IPM strategies would be helpful in order to provide a better understanding of the most effective components that yield the biggest impact. Further, a cost-benefit analysis of different combinations of components of IPM strategies would also be helpful, in order to provide evidence for wider dissemination and the up-scaling of the technologies.

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