

Awareness and Attitude towards Mango Infesting Fruit Flies and Adoption of an IPM Strategy: A Panel Data Analysis in Elgeyo Marakwet, Kenya

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Abstract
This study aimed at understanding farmers' awareness and attitude towards mango infesting fruit flies, the adoption of an IPM strategy, and the determinants of farmers' knowledge and perceptions on fruit fly infestation and management. We utilized panel data collected from 608 mango farmers in Elgeyo Marakwet County, Kenya. Descriptive results show that eighty four percent of farmers reported high damage caused by fruit flies. The most common identified fruit fly symptoms were infected fruits that contain maggots and fruits falling off the plant prematurely. Fruit fly traps and orchard sanitation by feeding infested fruits to animals and burying infected mangoes were well-known and adopted IPM strategies among the farmers. The principal component analysis (PCA) was employed to develop the knowledge and perception index that was subsequently used in multiple regression analysis. The regression estimates indicate that farmers' awareness and attitude towards fruit fly infestation and management is positively associated with gender of the household head, training on IPM, contact with an extension officer, membership to a mango cooperative, and experience of pesticide intoxication, while age of the household head and mango income negatively influenced farmers' awareness and attitude on fruit fly infestation and management. We emphasize on the role of rural institutions and associations in enhancing farmers' knowledge and perceptions on fruit fly infestation and management through improved product-specific training, access to farmer cooperatives and extension services on non-pesticide methods of suppressing fruit flies.
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1. Introduction

Horticultural farming is the fastest growing agricultural sector in Sub-Saharan Africa (SSA) where mango is considered a fundamental source of nutrition, income and employment particularly in Kenya (Ndlela *et al.,* 2017). Mangoes contribute to 20% of the total fruit production value and its production has increased over time, from below 250, 000 metric tonnes in 2003 to over 746,377 metric tonnes in 2018 (Horticultural Crops Directorate (HCD), 2018). Despite the economic and nutritional contribution of mangoes, mango production is often constrained by infestation of insect pests and diseases (Nelson, 2008a; Nelson, 2008b; Nakinga *et al.*, 2014).

The most cited pest is the fruit flies that are a great threat to mango production and marketability (Rwomushana *et al.*, 2008; Vayssières *et al.*,2009). It is estimated that fruit flies cause annual losses of US$2 billion due to quarantine restrictions on the pest (Ekesi *et al.,* 2016). Hence, this limits the expansion of domestic and international trade of tropical fruits like mangoes, causing huge economic losses that deny producers revenue. To control pests like fruit flies, farmers in developing countries, including Kenya, heavily rely on chemical pesticides to intensify horticultural production (Carvalho, 2017). However, increased use of pesticides has harmful effects on the environment and human health (Midingoyi *et al.*, 2019; Mwungu *et al.*, 2020). Pesticides are also ineffective in controlling pests due to their inability to access the internal fruit tissue and are costly for resource-poor farmers (Gautam *et al.,* 2017).

As a result of the above challenges, Integrated Pest Management (IPM) has evolved as a shift from the conventional use of chemical pesticides towards biological, cultural and physical pest control strategies (Hazell & Wood, 2008). The International Centre for Insect Physiology and Ecology (*icipe*) has spearheaded the development and implementation of the fruit fly IPM strategy together with its partners from Europe, Asia, Africa and the United States of America. The fruit fly IPM package consists of the spot application of food bait, the male annihilation technique (MAT) (also known as the fruit fly trap and lure), biological control using biopesticides and parasitoids, and orchard sanitation using an augmentorium (Ekesi *et al.*, 2014; Ekesi, 2015).

Adoption of the fruit fly IPM components has led to economic, environmental and health benefits to farmers (Muriithi *et al.*, 2016; Midingoyi *et al.*, 2019; Mwungu *et al.*, 2020), however, adoption of the IPM strategy is very slow (Wangithi *et al.*, 2021). To accelerate IPM adoption, enhancing farmer's knoweldge and perceptions of IPM is the first step and is critical (Akotsen-Mensah *et al*., 2017). Most previous studies show that training is highly correlated with farmers' knowledge and perceptions of pest management strategies. For instance, Yang *et al*. (2008) indicated that farmers who attended the field school in Yunnan province in China, from 2003 to 2007, had significant gains of knowledge on vegetable pests and management strategies. Furthermore, Waddington *et al*. (2014) and Gautam *et al*. (2017) emphasize that training is efficient in improving farmers' knowledge about pests and perceptions of IPM.

Although the aforementioned studies assess the knowledge and perceptions of farmers towards pests and IPM, none of these studies utilize panel data for their analysis. For instance, Wangithi *et al*. (2021) evaluates farmers' awareness and use of non-pesticide practices for management of fruit flies using cross-sectional data from Embu County, Kenya, while Muriithi *et al*. (2021) also adopts cross-sectional data collected from 365 households to assess farmers' knowledge and perceptions on fruit flies and their willingness to pay for fruit fly IPM in Ethiopia. Similarly, studies done by Sadique (2020) and Allahyari *et al*. (2017) obtain and analyze cross-sectional data to measure farmers' technical knowledge and perceptions on IPM. Therefore, this study builds on literature on the awareness and attitudes of farmers towards fruit fly infestation and management using panel data. Apart from training, we also provide empirical evidence on other determinants of farmers' knowledge and perceptions on fruit fly infestation and management using the principal component analysis. The study first assesses farmers' demographic characteristics, severity and symptoms of fruit fly infestation, and farmers' knowledge and adoption of fruit fly IPM. Secondly, we empirically determine factors that influence farmers' knowledge and perceptions on fruit fly infestation and management.

The study utilized baseline and end line data collected from mango farmers in Elgeyo Marakwet County, Kenya. The results show that the severity of fruit fly infestation was high as reported by 84% of farmers. The most common symptoms of fruit fly infestation were infected fruits that contain maggots and fruits falling off the plant prematurely. Furthermore, fruit fly traps and orchard sanitation by feeding infested fruits to animals and burying infected mangoes were commonly known and practiced by farmers. The regression results indicate that sex of the household head, training on IPM, extension contact, membership to a mango cooperative, and experience of pesticide intoxication positively influence farmers' knowledge and perceptions on fruit fly infestation and management, while age of the household head and mango income negatively influence the awareness and attitude of farmers towards fruit fly infestation and management. These results are presented and discussed in this paper.

2. Methodology

2.1 Data and Sampling Procedure

This study utilized data obtained from baseline and end line household surveys with mango farmers in Elgeyo Marakwet. Elgeyo Marakwet County was purposively selected from the main mango growing Counties in Kenya due to the intensity of mango production in the area. Data collection was implemented following a multi-stage sampling procedure. Six wards in the major mango producing areas of Elgeyo Marakwet were selected, namely Endo, Sambirir, Arror, Emsoo, Soy North, and Soy South. Villages and mango farmers were then sampled from the mango growing wards prepared and compiled by *icipe's* research team. Sixty-six (66) villages were randomly selected from the six wards using the probability proportional to size (PPS) sampling procedure, and 663 mango growing households were randomly selected for baseline interviews conducted in October 2017.

The end line survey was conducted in June 2019, revisiting the same households interviewed at baseline. Six hundred and eight (608) households were successfully interviewed, leading to an attrition of 8%. Data was collected by trained enumerators using structured closed-ended questionnaires programmed in a Census and Survey Processing System (CSPro) software during the face-to-face interviews. The data was then transferred and analyzed using STATA 14 and SPSS 22 statistical software. Baseline data analyzed include the demographic characteristics of mango farmers, the severity and symptoms of fruit fly infestation, and the knowledge and adoption of fruit fly IPM components. Data on farmers' knowledge and perceptions on fruit fly infestation and management was obtained from the end line survey.

2.2 Principal Component Analysis (PCA) Method

We used the PCA method to generate factors that strongly describe farmers' knowledge and perceptions on fruit fly infestation and management. The PCA method was employed to summarize farmers' knowledge and perception variables into aggregates and to generate independent factors for subsequent use in regression analysis. Therefore, relevant information was extracted from the set of variables and reduced to provide meaningful information (Vyas & Kumaranayake, 2006). The principal components were validated by the Kaiser-Meyer-Olkim (KMO) test, where values >0.6 are ideal and components with eigen values >1 are selected (Kaiser, 1974). The eigen values allowed the retention of factors that significantly describe a large amount of variation from the original data (Asai *et al*., 2014). Additionally, factor loadings were subjected to an orthogonal varimax rotation to produce uncorrelated factor solutions that are easy to interpret.

The knowledge and perception (KP) index was generated using the weighted sum scores (Filmer & Pritchett, 2001) with modification to the study context:

$$KP_i = \sum_{i=1}^{j} \lambda_j (x_{ij} - \mu_j)/\sigma_j \quad (1)$$

where KP_i is the knowledge and perception index; λ_j is the factor loading of the jth knowledge and perception statement; x_{ij} is the response of the ith farmer for the jth knowledge and perception statement; μ_j and σ_j are the mean and standard deviation of the jth knowledge and perception statement, respectively.

2.2.1. Empirical Strategy

This study utilized the ordinary least squares (OLS) model to determine the factors influencing farmers' knowledge and perceptions on fruit fly infestation and management. The dependent variable of the model was the KP index derived using the PCA and the independent variables included household and socio-economic attributes of farmers. The OLS model was well suited for our data due to the continuous nature of our dependent variable and because the OLS estimates are best linear unbiased estimators with minimum variance (Montgomery *et al*., 2021). The OLS regression was estimated as a linear function as follows:

$$Y_n = \alpha + \lambda_i X_i + \varepsilon \quad (2)$$

where Y_n is the nth factor score; X_i represents a vector of observed covariates; and ε is the stochastic term. The coefficient α is the y-intercept; and λ_i denotes a vector of the marginal coefficient effect of the observable independent variables (X_i).

2.3. Description and Measurement of Variables

The knowledge and perception index was generated based on 7 statements as shown in Table 6. Farmers were asked to rate their level of agreement or disagreement on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The PCA was used to reduce and group the statements into a knowledge and perception index with values ranging from -8.47 to 3.68. The statements were mainly on farmers' perceptions of extension services, training and fruit fly IPM, specifically the fruit fly trap and lure (taken as one component) as a better management strategy, and on farmers' knowledge on fruit fly infestation. Positive values of the KP index signified good knowledge and perceptions on fruit fly infestation and management, and negative values indicated poor knowledge and perceptions on fruit fly infestation and management. The KP index was measured as a continuous dependent variable in the regression model (Table 1). Additionally, independent variables that were likely to affect the dependent variable were selected based on previous studies (Cockburn *et al*., 2014; Adam *et al*., 2015; Kassahun *et al.,* 2017; David & Abbyssinia, 2017).

Table 1: Definition of the dependent and independent variables

Description of Variables	Measurement
Dependent variable	
Farmers' knowledge and perception on fruit fly infestation and management	Knowledge and perception index (continuous)
Independent variables	
Sex of the household head	Male=1; Female=0
Age of the household head	Years
Education of the household head	Years
Marital status of the household head	Married=1; Not married=0
Mature mango trees	Count/Number
Mango income	Proportion of mango income out of total annual household income
Mango production loss caused by fruit flies	Percentage
Access to credit for agricultural inputs including IPM	Yes=1; No=0
Size of family labour	Count/Number
Attended training on IPM	Yes=1; No=0
Extension contact on non-pesticide methods of controlling pests	Yes=1; No=0
Member of a mango cooperative	Yes=1; No=0
Experience of pesticide intoxication or sickness	Yes=1; No=0

3. Results

3.1. Household and Demographic Characteristics of Mango Farmers in Elgeyo Marakwet

Descriptive results of household and demographic characteristics of mango farmers indicate that 95% of interviewed households are led by males (Table 2). The youngest mango farmer interviewed was 23 years and the oldest 78, with an average for all at 44 years. More so, the average number of years of formal education among these farmers is approximately 10 years which corresponds to Form 2 secondary level of education in the 8-4-4 education system of Kenya. About 92% of household heads reported to be married.

Table 2: Percentage of mango farmers by gender, marital status, mean age and education level

Variable	Observations	Mean	Std. Dev.	Min	Max
Sex=1 if male household head	607	0.95	0.21	0	1
Household head age (years)	607	43.94	12.23	23	78
Household head education level (years)	607	9.66	5.57	0	12
=1 if household head is married	607	0.92	0.26	0	1

3.2. Farmers' Mango Production Characteristics and Land Size Allocated to Growing Mangoes

In this survey, more than half of the mango farmers had attended training on IPM as shown in Table 3. Table 3 further reveals that only 26% of interviewed farmers were visited by agricultural extension officers who discussed non-pesticide means of controlling pests and about 12% of farmers belonged to a mango cooperative. Almost all households use family labour in mango production (99%) and the average size of family labour provided is approximately four people with some households involving a maximum of 14 family members in mango production. Interviewed farmers were majorly small-scale mango farmers with an average mango acreage of 0.59, although larger pieces of about 6 acres were reported. Additionally, the average total number of mature trees owned by mango farmers is 29 trees with some farmers having only 1 tree while other mango farmers owning 590 mature mango trees in their orchards.

The average percentage share of mango income from the total annual household income is 24% with a maximum value of 100%. Mango farmers also specified that they faced 27% of mango production loss due to fruit flies with some farmers experiencing extreme losses of about 96%. Furthermore, only 5% of mango farmers reported to have access to credit to purchase agricultural inputs including IPM and 20% of interviewed farmers stated that they have experienced pesticide intoxication or sickness before.

Table 3: Mean land size and mango production characteristics of farmers

Variable	Observations	Mean	Std. Dev.	Min	Max
=1 if farmer has attended training on IPM	607	0.57	0.49	0	1
=1 if farmer has been visited by extension officer	607	0.26	0.44	0	1
=1 if farmer is a member of a mango cooperative	607	0.12	0.33	0	1
Size of family labour (number)	607	3.83	2.04	0	14
Number of mature mango trees owned	607	28.97	35.68	1	590
Size of mango orchard (acres)	607	0.59	0.73	0.01	5.70
Percentage share of mango income	607	24.43	21.95	0	100
Proportion of mango production loss due to fruit flies	607	26.67	13.90	0	96
=1 if farmer received credit for agricultural inputs	607	0.05	0.21	0	1
= 1 if farmer has experienced pesticide intoxication or sickness before	607	0.20	0.40	0	1

3.3. Severity, Symptoms, and Knowledge of Fruit Fly Infestation and Management Strategies

Most of the farmers showed a degree of awareness of the pests and diseases that are attacking their mangoes. About 99% reported that they were aware of mango fruit flies (Table 4). Mango weevil was reported by 58% while 40% reported that they were aware of mango white scale. Regarding severity of damage, fruit flies were reported by 84% of farmers to cause high damage to their mangoes. Only 19% and 18% of interviewed farmers reported mango weevil and mango white scale respectively as causing high losses on yield and quality of their mangoes. Seventy-seven percent of respondents were aware of Anthracnose diseases while 59% were aware of Powdery mildew.

Table 4: Knowledge, damage and severity of mango pests and diseases (Percentages)

			Severity		
Pest	**Know**	**Damage**	**High**	**Medium**	**Low**
Mango fruit fly	98.81	99.48	83.94	12.57	3.49
Mango weevil	57.68	99.40	19.05	50.00	30.06
Mango white scale	39.76	97.39	18.34	43.23	35.81
Disease					
Anthracnose	77.26	99.11	55.90	29.18	14.25
Powdery mildew	59.62	97.98	37.18	34.87	25.94

Mango farmers were knowledgeable of the symptoms of fruit fly infestation. The major mango fruit fly infestation symptom that farmers identified was infested fruits that contain maggots (33%). Other symptoms reported by farmers were fruits falling off the plant prematurely (32%), rotten fruits (20%), punctured fruits

(15%) and mangoes changing yellow (0.22%) due to over-ripening.

Analysis of farmers' awareness of the fruit fly IPM strategy showed that 88% had heard about IPM. Regarding IPM components, a majority (70%) were aware of fruit fly traps while 35% of the respondents were aware of feeding infected fruits to animals and 29% about burying infected fruits (Table 5). Fruit fly traps were being used by 25% of the surveyed mango growers while 23% fed the infected fruits to their animals. Eighteen percent of the farmers also practiced orchard sanitation by burying their infected fruits.

Table 5: Knowledge and adoption of fruit fly IPM components (Percentages)

Component	Know	Ever Used	Currently Using
Fruit fly traps/MAT	69.52	30.15	24.71
Food(protein)bait spray	2.14	0.66	0.66
Biopesticides for soil inoculation	0.82	0.16	0.16
Biological control using parasitoids	1.98	0.33	0.00
Orchard sanitation using augmentorium	0.66	0.66	0.00
Orchard sanitation using bagging/wrapping	2.97	1.32	1.15
Orchard sanitation by burying fallen infected fruits	29.49	19.60	17.63
Orchard sanitation by burning infected fruits	16.97	10.87	9.06
Disposing infected fruits by feeding to animals	35.26	25.37	23.39

3.4. Factors Influencing Farmers' Knowledge and Perceptions on Fruit Fly Infestation and Management

Table 6 presents the mean rankings of farmers' level of agreement towards the knowledge and perception statements based on a five-point Likert scale. The mean values range between 2.49 and 4.54 with values closer to five indicating more knowledge and favourable perceptions, and values near to one signifying less knowledge and favourable perceptions on fruit fly IPM for the first six statements in Table 6. For the 7th knowledge and perception statement, mean scores closer to one indicate good knowledge and favourable perceptions and scores closer to five indicate poor knowledge and less favourable perceptions towards fruit fly IPM.

The statement, "*Spread of fruit flies can be prevented using traps and lures*" had the highest mean score ranking of 4.54. Mango farmers also indicated that they were knowledgeable that infected fruits in the field can increase fruit fly infestation as shown by the mean score of 4.46. Additionally, respondents had favourable perceptions towards training and extension services, fruit fly IPM (traps and lures) as better alternatives to synthetic chemicals, reporting fruit fly infestation to agricultural extension officers, the health benefits of using fruit fly IPM over synthetic chemicals, and the ineffectiveness of using synthetic chemicals only to control fruit flies.

Table 6: Mean rankings of farmers' knowledge and perceptions on fruit fly infestation and management

Knowledge and perception statement	Mean	SD	Rank
Spread of fruit flies can be prevented using traps and lures.	4.54	0.70	1
Infected fruits in the field can host many fruit fly eggs that develop into maggots.	4.46	0.72	2
Training and extension services are appropriate for providing information on fruit fly management.	4.42	0.75	3
Fruit fly traps and lures are better alternatives to synthetic chemicals for the control of mango fruit flies.	4.21	0.92	4
Reporting fruit fly infestation to agricultural extension officers is important for government intervention.	4.11	0.96	5
Synthetic chemicals pose a great risk to human health compared to the use of fruit fly traps and lures.	3.90	1.08	6
Synthetic chemicals alone can effectively control fruit flies.	2.49	1.13	7

Note: Statements are based on a 5-point Likert scale:1=Strongly disagree, 2=Disagree, 3=No opinion/don't know, 4=Agree, 5=Strongly agree.

The OLS regression results of the factors influencing farmers' knowledge and perceptions (or farmers' awareness and attitudes) on fruit fly infestation and management is presented in Table 7. The value of R-squared implies that 10% of the variation in our dependent variable is explained by the covariates included in the regression which is a significant improvement from the null model as indicated by the significant F-statistic (Table 7). Results of the factor loadings from each of the 7 statements are presented in the Appendix (Table A1). The KMO test is 0.75 (>0.6) and the Bartlett's test of sphericity is significant at 1%, indicating a significant relationship among the statements. Further, the retained factors cumulatively explained 37% of the variation (Table A1). Although only five statements had factor loadings above the recommended threshold of 0.5 as indicated by Okello, *et al*. (2021), all the 7 statements were used to calculate the KP index.

The regression results show that the sex of the household head, age of the household head, mango income, training attendance, extension contact, membership to a mango cooperative, and experience of pesticide intoxication or sickness significantly influence the knowledge and perceptions of farmers on fruit fly infestation and management[1]. A unit increase in the sex of the household head being male increases the knowledge and perception index by 1.78 units, however, as the age of the household head increases by a unit, the knowledge and perception index declines by 0.02 units.

Interestingly, a unit increase in mango income significantly reduces the knowledge and perception index by 0.01 units, and training attendance on IPM proves to greatly increase the knowledge and perceptions of mango farmers on fruit fly IPM by 1.09 units as shown in Table 7. As expected, increased visits by extension officers who discuss non-pesticide means of controlling fruit flies significantly improves farmers' knowledge and perceptions on fruit fly IPM by 0.42 units, and membership to a mango cooperative also advances the knowledge and perceptions of farmers towards fruit fly IPM by 0.85 units.

Regarding pesticide intoxication/sickness, farmers who experience pesticide intoxication or sickness are more likely to be aware and have positive attitudes towards fruit fly IPM. A unit increase in farmer exposure to pesticide intoxication leads to an increase in the knowledge and perception index by 0.51 units.

Table 7: Ordinary least square regression (Knowledge and perception)

Variables	**Estimates**
Sex of the household head (dummy)	1.78**
	(0.83)
Age of the household head (years)	-0.02*
	(0.01)
Education of the household head (years)	0.01
	(0.01)
Marital status of the household head (dummy)	-0.43
	(0.60)
Mature mango trees (number)	0.00
	(0.00)
Mango income (percentage share of total annual household income)	-0.01**
	(0.00)
Mango production loss caused by fruit flies (percentage)	-0.00
	(0.01)
Access to credit for agricultural inputs (dummy)	0.13
	(0.47)
Size of family labour (number)	-0.01
	(0.05)
Training attendance on IPM (dummy)	1.09***
	(0.24)
Extension contact (dummy)	0.42*
	(0.23)
Member of a mango cooperative (dummy)	0.85***
	(0.29)
Experience of pesticide intoxication or sickness (dummy)	0.51**
	(0.25)
Constant	-1.28*
	(0.67)
Observations	607
R^2	0.10
F-value	4.76***

*Note: Significance level: *** p<0.01, ** p<0.05, * p<0.1. Clustered robust standard errors at village level are in parenthesis.*

4. Discussion

4.1. Household and Demographic Characteristics of Mango Farmers in Elgeyo Marakwet

In this study, we aimed to first characterize mango farmers in Kenya. Results show that 95% of mango producing households are led by males. This suggests a higher involvement of males in mango crop management especially in providing labour, although both males and their spouses could be involved in plot management and

[1] From this point onwards, we also refer to farmers' knowledge and perceptions on fruit fly infestation and management as farmers' knowledge and perceptions on fruit fly IPM since the 7 knowledge and perception statements were on fruit fly IPM, particularly on the use of fruit fly traps and lures that are taken as a whole fruit fly IPM component/strategy.

decision-making for increased income (Bjornlund *et al*., 2019) as 92% of household heads in this study are married. Household heads were found to be agile and young with an average of 44 years and are therefore more likely to adopt new labour-intensive technologies. This is because younger farmers are less-risk averse and more willing to adopt new technologies (Mwangi *et al*., 2015), however, if the technology is capital intensive, young farmers may not adopt as their resources are often limited.

Formal education has been significantly correlated with adoption of management practices (Kikulwe & Asindu, 2020). In this study, most mango farmers had attained 10 years of formal education hence they are able to comprehend knowledge intensive technologies such as the fruit fly IPM (Ghimire *et al*., 2015). Only 26% and 12% of mango farmers had contact with extension officers and were members of a mango cooperative, respectively. These percentages are relatively low, thus farmers' access to extension services and membership to a mango cooperative needs to be improved significantly as they are appropriate channels and platforms for the transfer of knowledge on improved technologies such as IPM (Zwane, 2012; Midingoyi *et al.*, 2019).

Findings further reveal that family labour is crucial in mango production. On average, 4 family members were involved during mango production. This is plausible as family labour is required for orchard sanitation which is a labour-intensive fruit fly IPM component required to reduce fruit fly infestation by burning and burying mango infested fruits, feeding them to livestock or disposing fruits in an augmentorium (Ekesi, 2015). The study represented small-scale farmers with an average land size of 0.59 acres of mangoes and an average number of 29 mature mango trees. This highlights the economic and nutritional value of mangoes to small-scale farmers as mango is a major food security crop accounting for much of farmers' income and is ranked second most important fruit after banana in Kenya (HCD, 2018).

The average share of mango income from the total annual income is 24% which coincides with Wangithi *et al.* (2021) who reported that mango farmers in Embu County, Kenya received 29% of their annual household income from selling mangoes. A major challenge faced in mango production among farmers in Elgeyo Marakwet is fruit fly infestation where the average mango production loss attributed to fruit flies is 27% which implies the seriousness and economic importance of fruit flies in mango production (De Meyer *et al*., 2014). In this study, access to credit among mango farmers is relatively low which is most likely to limit the purchase of agricultural inputs including IPM (Mwaura *et al*., 2021). Furthermore, farmer exposure to pesticide intoxication is most likely to create a shift towards knowledge acquisition, positive attitudes and adoption of IPM strategies that are environmentally friendly and less harmful to human beings (Mwungu *et al*., 2020).

4.2. Severity, Symptoms, and Knowledge of Fruit Fly Infestation and Management Strategies

About 99% of farmers were aware of fruit flies as a devastating pest attacking their mangoes. This is not surprising as most farmers in SSA have shown a degree of knowledge about fruit flies. For instance, in Ghana, farmers showed a depth of knowledge by identifying *Bactrocera dorsalis,* a fruit fly species, as more damaging than the mango weevil and mango white scale in terms of loss of market value, and rejection of mangoes in international markets (Abdullahi *et al*., 2011; Benjamin *et al*., 2012). This reflected the economic importance of fruit flies to farmers in SSA.

The economic importance of fruit flies is further demonstrated by the severity of damage reported by our respondents. Eighty-four percent of mango growers reported high damage caused by the fruit flies, unlike the mango weevil and mango white scale that were reported to have less damage on mangoes. Fruit flies attack mangoes leading to 40-80% losses depending on the locality, variety and season (Rwomushana *et al*., 2008; Vayssières *et al*.,2009). Furthermore, it is possible to experience 100% losses across agro-ecological zones without control measures (Nakinga *et al*., 2014). Thus, it is important to control fruit fly infestation to avoid huge economic losses. Regarding diseases, anthracnose and powdery mildew were reported as the major diseases affecting mangoes in Elgeyo Marakwet. Both are fungal diseases that attack the flowers and fruit of a mango tree (Nelson, 2008a; Nelson, 2008b).

Our results further reveal that mango farmers were knowledgeable of fruit fly infestation symptoms. The main identified symptoms were infested fruits that contain maggots, fruits falling off the plant prematurely, rotten fruits, punctured fruits, and mangoes changing yellow. These symptoms arise when the female fruit fly punctures and lays eggs on the young fruit of the mango tree that is attractive as it approaches maturity. Then the larvae/ maggots create tunnels in the flesh of the untreated mango, providing an opportunity for secondary infections. This hastens the maturation of the mango, which later falls to the ground. The larvae then leave the rotten fruit and develop into pupae in the top layer of the soil. The pupae develop to an adult that starts to look for nourishment to reach sexual maturity, mate, and lay eggs (Ekesi & Billah, 2007; Rattanapun, 2009).

Agricultural literature suggests that awareness of symptoms of pest infestation and new technologies are the first steps in the adoption process (Waddington *et al*., 2014; Korir *et al*., 2015). Analyzed data indicates that 88% of mango farmers were aware of IPM strategies, specifically fruit fly traps, feeding infected fruits to animals and burying infected fruits. The commonly used IPM strategies among respondents were fruit fly traps, feeding infected fruits to animals, burying and burning infected fruits. Farmers adopted these strategies possibly because fruit fly traps are currently available in the market, while orchard sanitation by feeding infected fruits to animals, burying and burning infected fruits is a simple cultural practice that only requires family labour ((Ekesi *et al*., 2014; Ekesi, 2015). However, results show that although farmers demonstrated good knowledge of IPM strategies, adoption levels were still low. This result coincides with Wangithi *et al*. (2021) who concluded that some famers who were aware of IPM still did not adopt IPM strategies.

Regarding the most commonly used fruit fly IPM components, the fruit fly trap involves the use of a male lure that traps the male flies to reduce their population to low levels such that mating does not occur (Ekesi & Billah, 2007). Muriithi *et al*. (2016) and Midingoyi *et al*. (2019) prove that the use of fruit fly traps alone can result in significant yield gains. However, the use of orchard sanitation alone may not yield a significant impact. A combination of fruit fly traps and orchard sanitation, which are both affordable, easy to apply and maintain IPM strategies, is most likely to result to a significant impact on mango fruit fly control (Muriithi *et al*., 2016).

4.3. Factors Influencing Farmers' Knowledge and Perceptions on Fruit Fly Infestation and Management

The PCA method was utilized to generate the knowledge and perception index as the dependent variable in the OLS regression. Our R-squared is relatively low (10%), but according to Greene (2012), it is not unusual to report a low goodness of fit in empirical analysis especially in behavioural studies. The regression results indicate that male household heads were significanly knowlegeable and had good perceptions towards fruit fly IPM compared to female household heads. This is plausible as males dominate as household heads in our study. Additionally, male household heads are more likely to be mobile and have access to information on new technologies unlike rural women who are perceived to be less pro-actvie and confined to their households due to traditional obligations (Atreya, 2007). An increase in the age of the household is associated with a decrease in farmers' knowledge and perceptions on fruit fly infestation and management. This is a contradictve result to Wangithi *et al*. (2021), and can be explained by the fact that younger farmers are able to easily comprehend new technologies and apply labour intensive strategies of fruit fly IPM such as orchard sanitiation, unlike older farmers.

Interestingly, farmers with a higher share of mango income had lower levels of knowledge and attitude towards fruit fly IPM compared to farmers with a low share of mango income. An explanation is that probably farmers with a higher mango income have a low propensity to demand and acquire knowledge about new technologies such as fruit fly IPM to increase their mango production and income compared to farmers with a lower share of mango income. We also found that training on IPM significantly improves farmers' knowledge and perceptions on fruit fly IPM. This coincides with previous studies where training has been found to efficiently enhance the awareness and attitudes of farmers on fruit fly IPM, subsequently improving adoption (Korir *et al*., 2015; Gautam *et al*., 2017). This suggests the importance of knowledge acquisition and changing farmers' attitudes towards IPM through product-specific training to accelerate the dissemination and adoption of IPM technologies (Peshin *et al*., 2009; Cockburn *et al*., 2014).

The significance of extension services has been overemphasized in earlier studies (Zwane, 2012; Muriithi *et al*., 2016; Wangithi *et al*., 2021). In this study, farmers with extension contact to information on non-pesticide control measures were knoweldegable and had good perceptions on fruit fly IPM. This reveals extension services as appropriate dissemination channels for fruit fly IPM strategies. More so, membership to a mango cooperative is crucial for access to information on fruit fly IPM as revealed in our study. This result concurs with Midingoyi *et al.* (2019) and Mwungu *et al*. (2020) on the importance of rural institutions and associations to up-scale fruit fly IPM strategies.

We also found that farmer exposure to pesticide intoxication or sickness increases the chances of knowledge acquisition and improves farmers' perceptions towards adopting IPM technologies such as fruit fly IPM. This is possible as farmers who have experienced pesticide intoxication will opt for more environmentally and health friendly control and pest management strategies like IPM as emphasized by Midingoyi *et al*. (2019) and Mwungu *et al*. (2020).

5. Conclusion and Policy Implications

This study highlights farmers' awareness and attitude towards mango infesting fruit flies and the adoption of an IPM strategy. This was achieved by assessing the severity and common symptoms of fruit fly infestation, farmers' knowledge and adoption of fruit fly IPM components and by evaluating the determinants of farmers' knowledge and perceptions on fruit fly IPM. The study used panel data collected from 608 mango farmers in Elgeyo Marakwet, Kenya. Descriptive statistics using percentages and the ordinary least square regression were adopted for analysis.

Descriptive results reveal that the severity of damage caused by fruit flies is high compared to the damage caused by the mango weevil and mango white scale. We find mango farmers to be knowledgeable of fruit fly infestation symptoms. Farmers identify infested fruits that contain maggots, fruits falling off the plant prematurely, rotten fruits, punctured fruits and mangoes changing yellow as the most common symptoms.

Analyzed data also shows that the male annihilation technique is a well-known IPM strategy adopted by majority of farmers to suppress fruit flies.

The empirical results show a positive relationship between farmers' knowledge and perceptions on fruit fly IPM, and gender, training attendance on IPM, extension contact, membership to a mango cooperative and farmer exposure to pesticide intoxication. Training attendance on IPM had the greatest effect on farmers' awareness and attitudes towards fruit fly IPM. This suggests a useful dissemination strategy that allows farmers to appreciate and learn more about new technologies such fruit fly IPM. On the other hand, mango income and age had a negative association with farmers' knowledge and perceptions on fruit fly IPM. We found that younger mango growers were knowledgeable and had good perceptions of fruit fly IPM compared to older farmers. This may be because younger farmers can easily comprehend knowledge-intensive technologies such as fruit fly IPM.

Our results, therefore, emphasize on the major role of social network and rural institutions among farmers to improve their awareness and attitudes on new technologies and subsequently accelerate extensive adoption. This means that product-specific training on IPM, provision of extension services on non-pesticide ways of controlling pests and strengthening farmer cooperatives are crucial for farmer development through diffusion of knowledge and widespread adoption of agricultural technologies like fruit fly IPM in SSA.

Appendix

Table A1: Factor loadings of the knowledge and perception statements

Knowledge and perception statement	Rotated Components
1. Spread of fruit flies can be prevented using traps and lures.	0.70
2. Infected fruits in the field can host many fruit fly eggs that develop into maggots.	0.53
3. Training and extension services are appropriate for providing information on fruit fly management.	0.70
4. Fruit fly traps and lures are better alternatives to synthetic chemicals for the control of mango fruit flies.	0.71
5. Reporting fruit fly infestation to agricultural extension officers is important for government intervention.	0.64
6. Synthetic chemicals pose a great risk to human health compared to the use of fruit fly traps and lures.	0.42
7. Synthetic chemicals alone can effectively control fruit flies.	-0.49
Eigen value	2.59
Cumulative variance explained (%)	37.04

Note: Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy=0.75; Bartlett's test of sphericity: Chi-square (df)= 691.74 (21), p-value=0.00.

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