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Control of invasive *Liriomyza* leafminer species and compliance with food safety standards by small scale snow pea farmers in Kenya

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ABSTRACT

The Kenyan horticultural industry faces a new challenge following invasion by the quarantine *Liriomyza* leafminer species *Liriomyza huidobrensis*, *Liriomyza sativae* and *Liriomyza trifolii* which have recently become pests of economic importance. Controlling *Liriomyza* leafminers poses serious difficulties due to their biology and quarantine status. This paper examines farmers' awareness of the pests and difficulties faced in controlling them. (1) A questionnaire survey showed that snow pea farmers in Kenya rely mainly on pesticides for control of invasive *Liriomyza* leafminers; (2) Sixty five percent of respondents perceived pesticides to be ineffective; (3) As a result, 74% of respondents increased the frequency of pesticide applications, 61% increased dose rates and 58% used broad-spectrum insecticides to avert damage by the pests; (4) Snow pea farmers who signed contracts with exporters and whose production practices were monitored for compliance with Good Agricultural Practices (GlobalGAP) used fewer control strategies; (5) These findings imply that the pest status of *Liriomyza* leafminers is likely to increase and snow pea production will significantly decrease in Central areas of Kenya unless an integrated leafminer management strategy is developed and farmers educated on methods of identifying them in their early stages of attack and use appropriate chemicals and application methods.

1. Introduction

The horticulture industry is one of the most important sub-sectors that significantly contributes to the economic development of Africa because of its high economic returns, nutritive value and its ability to generate significant employment (Weinberger and Lumpkin, 2007; Ekesi, 2010). In Kenya, the horticultural industry generated US$ 1 billion in foreign exchange from exported commodities and over US$ 650 million domestically in 2008 (HCDA, 2009). It employed over 4 million people both on- and off-farm and contributed almost 13% of Kenya's Gross Domestic Product (HCDA, 2009). Total horticultural production was estimated to be close to 3 million tonnes which made Kenya one of the major producers and exporters of horticultural products in the world (Jaffee, 1995, 2003; HCDA, 2009; Ekesi, 2010). The European Union (EU) is the largest destination market for Kenyan horticultural produce and the USA and Asia are emerging markets. 80% of the production is by small scale farmers.

The Kenyan horticulture industry however face a new threat of invasion with some of the pests in the European Union's list of quarantine pests and this could undermine its EU based fresh produce export business. These pests are currently the most important cause of Kenya's fresh produce rejection in European market and *Liriomyza* leafminers constitute one of the leading quarantine pests that significantly affected vegetable production and fresh produces export (Kedera and Kuria, 2003; Njuguna et al., 2001; Chabi-Olaye et al., 2008).

The most common *Liriomyza* leafminer species in Kenya are: *Liriomyza sativae*, *Liriomyza trifolii* and *Liriomyza huidobrensis* (Chabi-Olaye et al., 2008). The three species attack a variety of crops of commercial value, which include snow pea (*Pisum sativum* L.), French bean (*Phaseolus vulgaris* L.), tomato (*Lycospersicon esculentum* Miller), runner bean (*Phaseolus coccineus*), potato (*Solanum tuberosum*) and a variety of cut flowers (Chabi-Olaye et al., 2008).

This study focuses on small scale farmers growing snow peas for export to the EU market, currently the major importer of Kenyan horticultural products.

Liriomyza leafminers are pests of unique economic importance on snow peas because they can attack the marketed part of the

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crop. The eggs laid on the fresh pods may often be unnoticeable until the produce has reached the destination market. If not controlled, *Liriomyza* leafminers could make Kenya lose its EU market through produce bans. In the mid to late 1990s, Guatemala lost its American market due to presence of *L. huidobrensis* in snow pea shipments to the USA resulting in over US$35 million annual loss in foregone revenue (Sullivan et al., 1999, 2000; Norton et al., 2003).

Control strategies used against leafminer pests however, must be in compliance with EU pesticide use restrictions and the GlobalGAP (formally known as Euro Retailers Produce Working Group on Good Agricultural Practices, EUREPGAP) standard, which mainly focuses on food safety, environmental protection, worker health and safety and animal welfare. All these are regulated through in-depth audits of production, postharvest produce handling and marketing systems (GlobalGAP, 2007).

The International Centre of Insect Physiology and Ecology (*icipe*) is working towards developing an Integrated Pest Management (IPM) programme for *Liriomyza* leafminers to reduce the yield losses and the growers' dependency from frequent pesticide applications. Their approach focuses on strategies that support the self-regulation of agro-ecosystems and seek sustainable solutions through the integration of biological control and rational use of pesticide.

The present study examines the current level of *Liriomyza* leafminers awareness and control strategies being employed by Kenyan snow pea farmers against the pests. The specific objectives of this study are: To analyze farmers' awareness about *Liriomyza* leafminer infestations and assess their current status at the farm level to analyze *Liriomyza* leafminer control strategies used by snow peas farmers and examine the factors affecting the choice of control strategies in snow peas production systems.

2. Materials and methods

2.1. Survey design and empirical methods

The study was carried out in the major snow peas growing areas of Nyeri and Imenti South Districts in Central and Eastern Provinces of Kenya respectively. The study started with focus group discussions prior to the survey. A questionnaire tool was designed and pre-tested based on the outcome of the focus discussions. A multistage sampling procedure was followed. The first stage involved purposive selection of the snow peas growing areas followed by grouping of respondents into two strata based whether they sold their produce in the spot market or were contracted by an exporter. A random sample of 220 respondents was taken and stratified in two strata: 120 spot market farmers and 100 contracted farmers.

The questionnaire was pre-tested in a different area from the study locations and final revision was made according to farmers' knowledge of snow pea production and associated problems. The questionnaire was administered by enumerators who had experience from previous cross-sectional data collection surveys under supervision. Data on farm and farmer characteristics, farmers' asset holding, income, production practices, knowledge of *Liriomyza* leafminers, the control strategies and snow peas yield reduction due to the pests' infestations at the farm level were collected. The information obtained through this quantitative survey was complemented with secondary data on produce interceptions and rejections due to presence of *Liriomyza* leafminers from Kenya Plant Health Inspectorate Service (KEPHIS). But no yield loss data were available for the pests.

The economic and production data including yield loss estimates were obtained through farmers' interviews. This study used both descriptive and quantitative analyses. Descriptive analysis was used to assess farmers' awareness of *Liriomyza* leafminers, farmers' ability to identify the pests and their damage symptoms, their perception of the extent of yield loss caused by the pests and the control practices employed. A multivariate regression model with robust standards errors was used to analyze the impact of farmers and farm characteristics on yield loss variations between different agro-climatic locations and groups of farmers. The yield loss was used as dependent variable. Following De Groote (2002) and Macharia et al. (2005), yield loss was estimated as follows:

Table 1
Variables used for quantitative analysis of determinants of the number of *Liriomyza* leafminer control strategies chosen by a farmer.

Type of variables	Variable definition
Dependent variables	
Q_{loss}	Proportionate yield loss
NumbControl	Number of control strategies
Independent variables	
DScore	Damage score [1 = low, 2 = Medium, 3 = High]
Experience	Years of experience in horticulture farming [Years]
Grp	Group membership [1 = Yes; 0 = No]
Gender	Gender of the respondents [1 = Male]
EDU	Level of education attained [0 = None; 1 = primary; 2 = Secondary; 3 = Tertiary]
AgriTraining	Training in agricultural practices [1 = Yes]
GlobalGAP	Acquisition of EUREPGAP certification [1 = Yes]
Market	Marketing strategy [1 = spot market, 0 = contract]
IdentifyLM	Leafminer awareness dummy [1 = Yes; 0 = No]
Biocontrol	Awareness of biological pest control
Credit	Credit dummy [1 = Yes, 0 = No]
lnIncome	Natural log of income [KES]
lnExpenditure	Natural log of expenditure on pesticide [KES]
District	District dummy (1 = Nyeri North, 0 = Imenti South)
lnAge	Natural log of age of the respondent [Years]
Distlocalmkt	Distance to the nearest local market [km]
Distagricoff	Distance to the nearest agricultural office [km]
Records	Keeping of production records [1 = Yes]
Extension	Access to extension support [1 = Yes]
HHAdults	Number of adults in the household

$$Q_{loss} = \frac{Y_p - Y_a}{Y_p} \times 100$$

where Q_{loss} is the percentage of yield loss estimate Y_p is the produce harvested in absence of *Liriomyza* leafminer (potential yields) and Y_a is the produce harvested during a period of heavy pest infestation (actual yield). The regression model was specified as follows:

$$Q_{loss} = X'\beta$$

where Q_{loss} is the dependent variable, X' is a vector of explanatory variables and β is a vector of coefficient estimates. Predictor variables are defined in Table 1 and include: damage score, farmer's income, pesticide cost, district dummy, gender, age, number of control methods, *Liriomyza* leafminer awareness, market strategy, distance to local market, distance to agricultural office, keeping of records, extension support, experience, number of adults in the household, education level and group membership.

Models for count data were used to analyze the determinants of the number of *Liriomyza* leafminer control strategies used by farmers. This is because of the discrete nature of the dependent variable (number of control strategies). The Poisson regression model which explicitly deals with characteristics of count variables (Greene, 2003) was fitted into the data. Following Greene (2008), the model was specified as follows:

$$E(y_i|x_i) = \exp(\alpha + X'\beta) \quad y_i = 0, 1, \ldots, i$$

Where y_i represents the number of control strategies chosen by a certain farmer i, X' is a vector of explanatory variables that determine the number of control strategies used by farmer i and β is a vector of unknown parameters to be estimated. The explanatory variables included in the model are shown in Table 1 and comprise of education level, awareness of biological control, leafminer damage score, timing of pesticide application, credit, income, pesticide expenditure, farming experience, district dummy, group membership, number of adults in the household, training in agricultural practices, record keeping, GlobalGAP certification and age. A statistical test for over dispersion was carried out. Following SAS Institute Inc. (2001), Deviance and Pearson Chi-Square divided by the degrees of freedom were used to detect over-dispersion or under-dispersion in the Poisson regression. A Pearson chi-square ratio of between 0.8 and 1.2 indicates that the Poisson regression model can be assumed to be appropriate in modeling the data (Trentacoste, 2000). For this case the ratio was found to be 0.74, an indication of the inappropriateness of Poisson model for analysis due to under-dispersion.

The general expression for under-dispersion can be presented as shown below (Greene, 2003):

$$V(y_i|x_i) = \widehat{\lambda}_i(1-\alpha)$$

where $E(y_i|x_i) = e^{X_i'\beta} = \widehat{\lambda}_i$.

The null hypothesis was specified as $H_0{:}\alpha = 0$ Against the alternative hypotheses $H_a{:}\alpha \neq 0$ an auxiliary OLS regression was used to estimate α following Cameron and Trivedi (1999) and Greene (2003).

$$z = \frac{\left(y_i - \widehat{\lambda}_i\right)^2 - y_i}{\widehat{\lambda}_i} = \alpha\,\frac{g\left(\widehat{\lambda}_i\right)}{\widehat{\lambda}_i} + \varepsilon_i$$

where ε_i is the error term, $\widehat{\lambda} = L = E(y_i|x_i) = e^{X'\beta}$

From the auxiliary regression, the coefficient α was found to be negative and statistically significant, a further evidence of under-dispersion and a violation of the basic assumption of equality of the mean and the variance imposed by the Poisson regression.

Negative binomial regression model was used instead. Following Greene (2007), the model was specified as

$$\mathrm{E}(y_i|x_i,\varepsilon) = \exp(\alpha + X'\beta + \varepsilon)$$

With variance $(y_i|x_i,\varepsilon) = \widehat{\lambda}_i - \alpha\lambda_i^2$

where $\widehat{\lambda} = \mathrm{E}(y_i|x_i) = e^{X_i'\beta}$, Y is the response variable, X' is a vector of explanatory variables and β is a vector of coefficients of the explanatory variables. ε is the stochastic error term.

Earlier application of negative binomial regression model in Kenya's horticulture industry was a study by Areal et al. (2008) to analyze cut flower interceptions due to quarantine pests in the UK market between 1996 and 2004. The study found that for some cut flower species such as Veronica and Carthamus, the probability of pest detection increased with increase in traded volumes. However, for most of the flower species analyzed, the study demonstrated that increase in volumes traded did not necessarily increase the risk of pest introduction in UK and that the cost of inspection could be reduced through proper targeting of inspection efforts.

3. Results and discussion

3.1. *Liriomyza* leafminer awareness among snow pea farmers

There was a high *Liriomyza* leafminer awareness among respondents (Table 2). Across locations, 96% of respondent farmers had heard about the *Liriomyza* leafminers, among which 88% considered the species as the major snow pea pest in the highland areas of Central Kenya (Table 2). A slightly higher number of farmers had heard about leafminer pests compared to those who could identify them. Identification was either through correct description of the pests in their adult stage or by damage symptoms caused by the larvae on the crops. Compared to other pests, many farmers in both districts perceived *Liriomyza* leafminers as major pest problems.

Table 2
Farmers' knowledge awareness and perception of *Liriomyza* leafminer (LMF) pests by location.

Location	LMF awareness			Recognition of LMF problem in the field		
	Heard about LMF? (%)	Can you identify LMF? (%)	Is LMF major pest? (%)	Symptoms on the crop (%)	Observing adult flies (%)	Symptom on plant and pods (%)
Ruguru	100	97	97	83	7	3
Kabaru	100	100	95	82	18	0
Naromoru	96	91	88	95	4	0
Kithangari	90	60	67	100	0	0
Igoki	84	64	64	95	5	0
Kaaria	100	88	96	61	0	9
Kathera	50	0	50	100	0	0
Abogeta	100	0	100	100	0	0
Total	96	88	88	87	7.7	1.5

Leafminer species belonging to the genus *Liriomyza* (Diptera: Agromyzidae) are important pests of various vegetable crops worldwide (Murphy and LaSalle, 1999). The most devastating pests in Kenya are *L. huidobrensis*, *L. sativae* and *L. trifolii*, representing >95% of total *Liriomyza* collected both in the cultivated and wild habitat (Chabi-Olaye et al., 2008). The quarantine species *L. huidobrensis* was the most important species (80%) in the highland, with pest infestation ranging between 10 and 80%, and was higher in cultivated than wild habitats (Chabi-Olaye et al., 2008).

The stage at which farmers identified *Liriomyza* leafminers on their farms was very important in determining the timing of control intervention especially pesticide application. On average, 87% of the farmers identified leafminers through damage symptoms on the leaves, about 8% in their adult stage and 2% through symptoms on the harvested produce respectively. Given that a rational farmer would intuitively initiate control after diagnosing pest in their farm, the findings suggest that majority of farmers target the protected larval stages. During this stage the larvae are sandwiched between leaf tissues and are therefore less likely to get into direct contact with the applied chemicals. This lack of optimal contact in combination with inappropriate selection of chemicals used could explain difficulties in dealing with leafminer infestations using pesticides. One possible effective way of controlling *Liriomyza* leafminers is through the use of biological products (Murphy and LaSalle, 1999).

3.2. Assessment of *Liriomyza* leafminer control strategies used by snow peas growers

The results of our study showed that farmers mainly rely on insecticides to control the pest and very few use cultural or biological control methods (Table 3). These control methods were used in combination rather than in isolation by snow pea farmers (Table 3). The study found that 74% of respondents increased frequency of pesticide application, 61% increased dosage rate and 58% used broad-spectrum insecticides to avert damage by *Liriomyza* leafminers. The results also showed that 40% of farmers interviewed avoided planting or reduced quantities of snow pea planted during periods when they anticipated high *Liriomyza* leafminer infestations. A similar behavioral response for *Liriomyza* was reported in

Table 3
Liriomyza leafminer pest control strategies used by snow pea farmers.

Control strategies[a]	Number of respondents	Percentage response
Spray more often	150	74
Scout for early detection	143	71
Increase pesticide concentration when one pesticide fails	124	61
Use broad-spectrum pesticides for the control of leafminers	118	58
Use selective pesticides	107	53
Encourage control of leafminers by natural enemies	92	46
Mix pesticides when one pesticide fails	89	44
Plant less snow pea and sugar snaps when incidence is high	81	40
Remove host plants that harbour leafminers	71	35
Create a barrier between the snow pea plot and other plots	71	35
Use bio pesticides	32	16
Use concoctions in control of *Liriomyza* leafminers	4	2

[a] Number of control strategies is a multiple response variable. Respondents reported to have used more than one strategy to tackle leafminer problem and in total there were 202 valid responses.

West Sumatra where farmers reduced the acreage of a susceptible potato variety by 40% (Rauf et al., 2000).

Farmers were asked to state whether from their experience, pesticides are effective in controlling *Liriomyza* leafminers and 65% perceived them as not effective. These results agreed with findings of Rauf et al., 2000, who found that 63% of farmers relied on chemicals for control of *Liriomyza* leafminers but 72% regarded chemical use as ineffective and uneconomical in controlling the pests. Similar results are also reported by Hidrayani et al. (2005) in their study on pesticide applications on Java potato fields. They had also established that pesticides used by farmers in controlling *Liriomyza* leafminers undermine the potential of antagonistic effects on natural enemies of the pests.

These findings corroborate those of Wilson and Tisdell (2001) who showed that farmers are more likely to use stronger concentrations of chemicals, increase the quantity and frequency of insecticide applications and increasingly mix several insecticides if they perceive chemicals as ineffective.

On-farm observations of pesticide applications made by small scale farmers in the study area showed that the quality of applications was often poor and/or ineffective. There were a number of different reasons for this including that unsuitable products were used. For example, the fungicide product Milraz (Propineb/cymoxanil) was used in an attempt to control *Liriomyza* leafminers, whereas it was not recommended for this pest. In some cases spray was not deposited evenly on the crop, standard sprayer nozzles were too coarse resulting in unnecessarily high volume application rates and coarse droplet spectra. Calibration was frequently not carried out accurately. This vicious cycle of insecticide misuse due to lack of knowledge of pest biology and spray timing led to increased insecticide use and compromised the ability of natural enemies to effectively control such pests. This puts to test the sustainability of agro-chemical dependent agricultural production.

Of ten most important pests of snow peas; *Liriomyza* leafminer stands out as the most damaging during high infestation (Table 4). Powdery mildew was ranked as the most important disease while aphids were considered as the second most damaging pests after *Liriomyza* leafminers (Table 4). Dimethoate is the most commonly used insecticide followed by abamectin and cyclone respectively (Table 5). The farmers' actual pesticide application rates are compared to the recommended rate in Table 5. Results further showed that 58%, 67% and 55% of interviewed farmers exceeded the recommended application rates of dimethoate, abamectin and cyclone respectively (Table 5). Other pesticides for which farmers applied an overdose include tebuconazole, deltamethrin, lambda-cyhalothrin, alphacypermethrin, Abamectin and alphacypermethrin. Results also showed that 100%, 83% and 34% of farmers applied an under dose of petroleum oil, propineb/cymoxanil and azadirachtin, respectively (Table 5). Most of the pesticides used with the exception of dimethoate were listed in exporters' recommended lists of pesticides. Most farmers correctly applied deltamethrin tablets probably because they are easy to use with only 18% applying overdose.

Table 4
Farmers' pest ranking in the snow pea production systems.

Pest/disease	Damage rating/farmers		
	Low	Medium	High
Leafminers	21	72	152
Powdery mildew	22	90	93
Aphids	49	120	84
Cutworm	54	86	36
Nematodes	7	18	30
Leaf spots	19	37	29
White rust	6	14	17
Blight	19	48	16
Thrips	16	31	14
Black spot	12	16	14

Results further showed that 70% of farmers scouted for *Liriomyza* leafminer pests in their farms, although majority of snow pea farmers are only able to recognize *Liriomyza* leafminer infestations using mines on the leaves. Even though scouting is an important component of integrated pest management for early detection of pest and disease problems, proper and timely diagnosis of the presence of *Liriomyza* leafminers is even more critical for appropriate intervention. This is not only important at farm level but also at a regional level given the high rate of *Liriomyza* spp. invasion and spread to new areas (Murphy and LaSalle, 1999; Ding et al., 2008).

3.3. Analysis of determinants of the number of control strategies used by snow pea farmers

Table 6 presents a negative binomial regression model fitted to examine the factors conditioning the number of *Liriomyza* leafminer control strategies chosen by farmers. Results showed that an increase in farmers' annual income increased the number of control strategies used by snow pea farmers. This finding may be capturing the effect of ability to purchase pesticides by those with higher incomes. Results presented in Table 3 already showed that many of the pest control strategies are insecticide based and that majority of farmers either applied under doses or over doses of recommended pesticides as shown in Table 5.

The results also showed that acquisition of GlobalGAP certification by respondents reduced the number of *Liriomyza* leafminer control strategies used. This implies that the types of control strategies being used by snow pea farmers to control *Liriomyza* leafminers were not compatible with good agricultural practices required under GlobalGAP standards. The strict monitoring and adherence to particular agricultural practices and pesticide application regime as required by GlobalGAP explain the reduced use of these practices. Going by these findings, Kenyan farmers are likely to lose the snow pea and flower export market niche.

3.4. Economic significance of invasive Liriomyza leafminer problems at farm level

The estimated yield loss due to *Liriomyza* leafminers varied significantly between locations (Table 7). The average snow pea

Table 5
Farmers' pesticide application practices in the snow pea production systems.

Product (active ingredient)	Application rate per 20 L pump			% of farmers who applied		
	Frequency ($N = 203$)	Actual rate	Recommended rate	Under dose	Correct dose	Over dose
Dimethoate (dimethoate)	52	32	30 ml	38	15	58
Dynamec (abamectin)	47	15	10 ml	11	22	67
Cyclone (cyclone)	17	26	30 ml	45	0	55
Folicur (tebuconazole)	14	10	15 ml	30	25	45
Decis tablet (deltamethrin)	33		1 tab	0	81	18
Decis (deltamethrin)	13	17	10 ml	7	17	76
Milraz (propineb/cymoxanil)	13	59	40g	34	45	21
DC Tron (petroleum oil)	12	60	100 ml	100	0	0
Karate (lambda-cyhalothrin)	10	27	20 ml	0	8	92
Achook (azadirachtin)	10	11	20 ml	83	4	13
Bestox (alphacypermethrin)	9	18	10 ml	27	36	37
Vapcomic (abamectin)	6	15	7 ml	0	0	100
Fastac (alphacypermethrin)	5	9	2.4 ml	0	5	95

yield loss in Nyeri and Imenti was 67% and 31%, respectively. In Nyeri, 49.6% of respondents reported higher yield losses ranging between 50 and 90%, representing over four times the number of farmers affected by the same range of yield loss in Imenti South (Table 7). Crop failure (yield loss > 90%) was reported by 21.7% of respondents in Nyeri compared to only 2.3% in Imenti. The variation in estimated yield loss between the two locations suggests that differences in agro-climatic conditions affect leafminer-related yield loss in snow pea. Nyeri North lies on the leeward side of Mt Kenya which is drier and warmer compared to Imenti South which is on the windward side of the mountain characterized by cool and wet climate. Previous studies have shown that *Liriomyza* leafminers have a shorter regeneration cycle in warmer conditions (Miller and Isger, 1985; Parrella, 1987; Petitt et al., 1991).

The accidental introduction of the invasive *Liriomyza* leafminers i.e., *L. huidobrensis*, *L. sativae* and *L. trifolii* to the African and Asian regions has caused considerable economic losses to horticultural crops (Murphy and LaSalle, 1999). For example, the introduction of *L. trifolii* caused serious damage to *Chrysanthemum* species in the lowlands areas of Kenya, resulting in the cessation of production and consequent loss of substantial exports (Spencer, 1985). In South Africa, *L. trifolii* caused considerable losses in tomatoes (*L. esculentum* Miller) (Kotzee and Dennill, 1996). Depending on crop stage and population level, *L. huidobrensis* caused up to 100% yield loss in potato crop (Shepard et al., 1998). Spencer (1973) reported yield losses of 50% in spinach and 54% in lettuce crop due to infestation of *L. huidobrensis*. In Mozambique, the same pest has been recorded to cause up 70% yield reduction of beans depending on time of planting and level of infestation (Davies, 1998).

The impact of farmer and farm characteristics on variation in yield losses was examined using both ordinary least squares (OLS) and robust regression with Huber-White heteroskedascity standard errors. Respondents from Nyeri North district are shown to experience 35% higher losses than their counterparts in Imenti South. As expected, the coefficient on number of control strategies has a negative sign implying that use of an additional control measure reduced losses by 2% (Table 8).

Members of farmer-groups were found to have 10% higher losses than non-members, other things constant. These farmers had restrictions on production practices and the types of insecticides they were permitted to use. Group members are not likely to try various control methods because their agronomic practices and pesticide use are closely monitored by exporters' technical advisors. Use of an additional control strategy reduced losses by 2%. Increase in the number of adults in the household was associated with a 2% reduction in losses. This is probably due to availability of additional labour for pesticide application given that most *Liriomyza* leafminer control measures are pesticide-based.

The variable capturing record keeping was significant at 5% level. Keeping of production records reduced losses by 10%, other things constant. These farmers were likely to evaluate effectiveness of various control methods and replace them with new ones if found ineffective. The results further show that there was a positive relationship between estimated yield losses and farmer's age. Older farmers incur 12% higher losses compared to their younger counterparts (Table 8). Results also showed that female farmers incurred 8% higher losses compared to their male counterparts (Table 8). These results suggested that older and female farmers are less likely to apply pesticides as often as their younger and male counterparts respectively. This is an important factor to consider when designing participatory *Liriomyza* leafminer control interventions that have training of farmers as a key component.

Table 6
Negative binomial regression estimates of factors affecting the number of *Liriomyza* leafminer control strategies used by farmers.

Number of control strategies	Estimate	S.E.	Z
Level of education attained	0.089**	0.044	2.000
Biological control awareness	0.066	0.090	0.730
Damage Score	0.016	0.024	0.680
LM Life cycle stage sprayed	0.007*	0.004	1.850
Access to Credit (dummy)	0.029	0.075	0.380
ln (farmers' annual income)	0.059*	0.035	1.660
Pesticide Expenditure	0.047	0.035	1.340
Yrs of experience in farming	−0.089	0.061	−1.460
District dummy	0.362***	0.116	3.130
Group membership	−0.121	0.091	−1.330
Number of adult in the Household	0.055***	0.021	2.620
Training in agricultural practices	0.064	0.074	0.870
Keeping production records	−0.072	0.077	−0.940
GlobalGAP certification	−0.193**	0.079	−2.430
ln (age of the respondent)	0.063	0.090	0.700
Number of observations	196		
Wald chi-squared (15)	3415.34		
Probability of chi-square	<0.0001		

Notes: ln = natural log, S.E. stand for standard error, *, **, and ***, estimate significant at 10, 5 and 1%, respectively.

Table 7
Comparison of snow pea yield loss due to *Liriomyza* leafminers attack in Nyeri North and Imenti South districts, 2008.

Range yield loss (%)	% Farmers responded	
	Nyeri North	Imenti South
0–49	28.7	86.1
50–90	49.6	11.6
>90	21.7	2.3
Average yield loss (%)	66.8a	31.2b

Notes: Within row, average yield loss followed by different lower case letter are significantly different ($t = 6.177$, $P < 0.0001$).

Table 8
Analysis of factors influencing variation in yield losses (analysis done across districts).

Parameters	OLS regression			Robust regression		
	Estimate	S.E.	t-value	Estimate	S.E.	t-value
Damage Score	0.072	0.037	1.95*	0.060	0.038	1.49
ln(income)	0.060	0.028	2.14**	0.060	0.029	2.17**
ln(pesticide cost)	−0.059	0.022	−2.63***	−0.050	0.023	−2.14**
District dummy	0.307	0.072	4.27***	0.350	0.073	4.77***
Gender dummy	−0.090	0.048	−1.88*	−0.080	0.048	−1.67*
ln(age)	0.116	0.060	1.94*	0.120	0.060	2.02**
Numb of Control	−0.019	0.009	−2.05**	−0.020	0.010	−2.27**
Leafminer awareness	−0.151	0.084	−1.8*	−0.150	0.085	−1.73*
Market strategy	−0.074	0.044	−1.68*	−0.070	0.045	−1.66
Distance to local market	−0.013	0.004	−3.06***	−0.020	0.004	−3.49***
Distance to agric off	−0.011	0.004	−2.45**	−0.010	0.005	−2.09**
Keeping of records	−0.076	0.048	−1.57	−0.100	0.049	−2.13**
Extension support	−0.055	0.055	−1.01	−0.060	0.055	−1.06
ln(experience)	−0.030	0.037	−0.82	−0.020	0.037	−0.59
No. adults/household	−0.025	0.014	−1.81*	−0.020	0.014	−1.74*
Level of education	−0.017	0.027	−0.63	−0.020	0.027	−0.55
Group membership	0.102	0.056	1.83*	0.100	0.056	1.76*
Intercept	0.096	0.391	0.24	0.002	0.395	0.0
Number of observation	151			151		
F (17, 133)	8.29			8.68		
P-value	<0.0001			<0.0001		
R-squared	0.5145					
Adjusted R-squared	0.4524					
Root MSE	0.21873					

4. Conclusion and policy implications

This study examined the challenges Kenyan small scale snow pea farmers face in controlling the *Liriomyza* leafminer pests. Results indicated that there was high level of awareness of the pests among small scale pea farmers although majority of them were only able to identify the pests by their symptoms namely mines on the snow pea leaves and pods. Most of control measures used against *Liriomyza* leafminers were pesticide-based. The findings showed up the weakness of some types of application carried out by farmers and demonstrated that there is a need for better information, training in spray application and use of additional IPM components to control *Liriomyza* leafminers.

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