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Occurrence and Damage Levels of *Thaumatotibia leucotreta* on Capsicum in Selected Counties in Lower Eastern Kenya

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Abstract: The false codling moth (FCM), *Thaumatotibia leucotreta* (Meyrick), is believed to have originated from Ethiopia and sub-Saharan Africa. Currently, this pest has extensively spread and is found in most parts of Africa, with records in approximately 40 countries in over 100 host plant species. Despite *Thaumatotibia leucotreta* being the leading cause of interceptions of Capsicum and cut flowers exported by Kenya to the European Union, information on abundance and damage levels inflicted on capsicum is limited. The objective of the study was to assess the abundance and damage levels of *T. leucotreta* on capsicum in the selected counties in Lower Eastern Kenya (Kitui, Machakos, and Makueni counties). Higher *T. leucotreta* larval density per farm was recorded in Kitui County compared to other counties. In farms with capsicum only (not intercropped with other crops), the mean number of FCM larvae was relatively higher in Kitui. Farming practices such as the use of uncertified seeds and seedlings and the excessive use of pesticides may be the major contributors to high larval incidence in Kitui County.

Keywords: occurrence; *Thaumatotibia leucotreta*; larval density; population; cropping system; farming practice

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1. Introduction

The false codling moth (FCM), *Thaumatotibia leucotreta* (Meyrick) (Lepidoptera: Tortricidae), is one of the economically important lepidopteran insect pests, and is believed to originate from sub-Saharan Africa [1–3]. The pest is polyphagous and attacks more than 70 host plants, including avocado (*Persea americana*), Citrus (*citrus* spp.), corn (*Zea may*), mangoes (*Mangifera indica*), cotton (*Gossypium herbaceum*), macadamia (*Macadamia integrifolia*), and capsicum (*Capsicum* spp.) [2,4]. Feeding and development of larvae on the pod, bolls, seeds, and cobs of the host plant affect its growth, resulting in premature fruit drop [3,5]. Damage to the fruit makes it more vulnerable to scavengers and reduces the quality of the fruit [6]. *Thaumatotibia leucotreta* also causes indirect losses through quarantine restrictions imposed by importing countries, hence reducing the profit margin for millions of farmers and value chain actors in sub-Saharan Africa. The interception of even a single larva in exported fruit or vegetables may result in the rejection of the entire shipment, underscoring the economic importance of this pest in the horticultural industry [4,7,8].

Capsicum, widely known as pepper, is ranked as the third most important vegetable in the world after potatoes and tomatoes [9]. The crop is believed to originate from Mexico and Central America [10,11]. In Kenya, capsicum is widely cultivated and consumed as a vegetable and spice [12]. According to the 2019 statistics, the total world production of capsicum was approximately 61 million tons, covering a cultivated area of about 4.5 million ha [13]. Approximately 9300 tons are produced annually in Kenya from an estimated acreage of 990 ha [14]. It is a high-value crop and its fruits are highly nutritious, produced

for both the domestic and export market. However, its production is constrained by insect pests and diseases, with the false codling moth *T. leucotreta* being one of the major threats. According to Adom et al. [3], an infestation of *capsicum* spp. by *T. leucotreta* within 5 months resulted in a 90% yield loss. This impoverishes the country due to lost income and food, as well as high production costs as a result of control measures [15]. For example, the detection of *T. leucotreta* in Kenya caused a ban on chilies exported to the United Kingdom and EU, resulting in an economic loss of up to USD 9 billion [16]. These quarantine restrictions also resulted in job losses along the value chain, especially in East Africa where millions of people are involved in capsicum production [17]. Furthermore, the direct feeding damage by *T. leucotreta* serves as an entry point for pathogens such as fungi and bacteria. These lower the quality of the infested produce, thereby affecting postharvest fruit market value. This is because aesthetic value is the primary criterion that is applied in determining the quality of fruit produce in the market [8,15,18].

Understanding the occurrence, damage, and spatial and temporal distribution of *T. leucotreta* is crucial for providing relevant information for the development of appropriate management strategies. A study by Mkiga et al. [19] described the population abundance of *T. leucotreta* in citrus farms in Kenya and Tanzania and revealed that the population abundance is higher between July and August. Although the occurrence and damage of *T. leucotreta* have been reported on citrus, okra, sweet pepper, African eggplant, and chili pepper under field and laboratory conditions [19], the infestation levels of this pest on these crops, except for citrus, are still unknown. In addition, farmers' perception of the pest infestation and factors that influence the population abundance of *T. leucotreta* on capsicum has not been determined. Such information is vital in decision-making, particularly in defining pest prevalence. Therefore, the objectives of this study were (i) to assess the abundance and damage levels of *T. leucotreta* on capsicum in the selected counties in Lower Eastern Kenya; and (ii) to determine farmers' perceptions of the infestation of *T. leucotreta* on capsicum.

2. Materials and Methods

2.1. Study Site

This study was conducted in eastern Kenya in the counties of Kitui (1°22′30.2916″ S, 37°59′42.7668″ E, 400 m to 766 m above sea level (a.s.l)), Makueni (1°35′–3°00′ S and 37°10′–38°30′ E, 995 m a.s.l), and Machakos (1°31′3.6624″ S and 37°15′48.294″ E, 1349 m a.s.l) between November and December 2021. The three counties are classified as semi-arid, with average annual rainfall ranging between 600 to 1150 mm and average minimum and maximum temperatures ranging between 25 to 30 °C annually. The rainfall pattern is bimodal, with short rain falling between October and December and long rains between March and April [20–22]. Most farmers in the three counties practice mixed farming, with major crops being fruit trees (mainly mango), mixed with cowpeas, sorghum, mung beans, beans, pigeon peas, and maize. Horticultural crops such as capsicum, onions, and tomatoes are grown under both rainfed and irrigation conditions. Farm size under capsicum production ranges between 0.1 to 3 acres. The main varieties of capsicum grown are California Wonder and Super Bell. However, other varieties such as bullet, long chilies, and demon are also grown in the three counties.

2.2. Sampling Procedure

A stratified random sampling approach was adopted in this study. Counties represented strata while farms were selected randomly based on the availability of the crop at the time of the survey. A total of 75 farms (28 Kitui, 24 Machakos, and 23 Makueni counties) were selected and visited in the three counties during the survey period. Capsicum farms were examined diagonally at random to assess the occurrence and damage of *T. leucotreta*. The occurrence was determined through the presence of the pest symptoms (Figure 1) including entry holes, the presence of frass, chewed skin, scars, the presence of eggs, discoloration, and the presence of *T. leucotreta* caterpillars on/in the fruit and pupae

in the soil. We sampled 10% of every 200 plants on each farm. A total of 50 fruits were collected from each farm and placed in khaki mafuco bags (Paperbags Limited, Nairobi Kenya), labeled, and transported to the Animal Rearing and Quarantine Unit at the International Centre of Insect Physiology and Ecology (*icipe*) for rearing. The size of the farm, GPS coordinates, and other crops grown on the farm were recorded. To understand farmers' knowledge, perceptions, and management practices against *T. leucotreta* in capsicum production areas, qualitative information was obtained during the sampling using administered well-structured questionnaires. Each farmer was interviewed face-to-face to collect information on respondent characteristics (e.g., age, education, and occupation), household characteristics (e.g., household income, farm size), cropping systems, source of seeds, farmers' knowledge of *T. leucotreta* and other pests, and management practices.

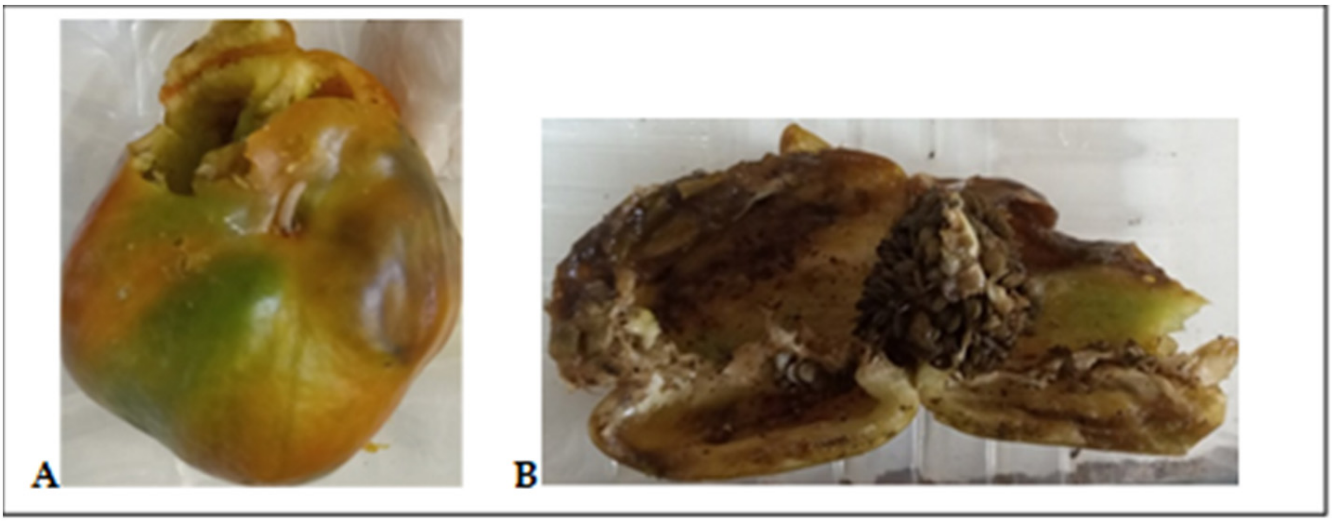

Figure 1. Presence of (**A**) exit holes and (**B**) frass on capsicum infested by FCM.

2.3. Factors Influencing the Population of T. leucotreta

2.3.1. Climate Factors

Climatic factors including temperature, relative humidity, and precipitation data were obtained from the online National Aeronautics and Space and Administration Prediction of Worldwide Energy Resource (NASA POWER)). This is provided on a global grid with a resolution of 0.5° latitude by 0.5° longitude on NASA POWER's website (http://power.larc.nasa.gov/, accessed on 4 February 2022). The provided data for these climatic parameters were recorded for the period between November and December. The specific point of analysis entered in the POWER interface was within surveyed areas in the selected counties, with the decimal degrees coordinates (latitude and longitude) converted to corresponding to degrees, minutes, and seconds format in the GPS format. Using Excel, the average of each variable per farm was obtained. These data were used to understand whether the population abundance of *T. leucotreta* in capsicum farms is affected by climatic factors. In addition, elevation and the cropping system (monocrop and intercrop) in each farm were determined and then used to assess their influence on the population abundance of *T. leucotreta*.

2.3.2. Human Factors

Well-structured questionnaires were administered to individuals during the survey in Makueni, Machakos, and Kitui Counties. The stratified random sampling procedure was used so that each capsicum-producing sub-county represented a stratum. The sub-counties were selected based on the availability of capsicum. In each sub-county, a local agricultural extension officer, community leaders, and a farmer were involved in the study to facilitate data collection. Interviews were conducted in local languages: English and Kiswahili. A

total of 135 farmers were randomly selected for interviews. The study targeted household heads; however, any adult in the household who knew about capsicum production was interviewed in cases where household heads were absent. The study focused on farmers' knowledge and perception of false codling moths and management practices applied by farmers to combat this pest. The questionnaire was discussed during face-to-face interviews with individual farmers. Some of the socio-demographic information that was addressed included age, gender, education, and occupation.

2.4. Sample Processing

Each fruit was accessed for *T. leucotreta* damage symptoms, weighed, placed in perforated plastic lunch boxes with sand provided as pupation media, and incubated for three weeks. The incubated fruits were dissected and the *T. leucotreta* larvae were counted. The fruits were checked daily until the final larval instar popped out to pupate in the soil. The pupae were monitored until the moths emerged. The moths were also counted. The moths were placed in cages for multiplication of the colony, at 25.0 ± 2.0 °C, 60% RH, and 12:12 L: D. Preparation of artificial diet and rearing were carried out following procedures described by [19,23]. The percentage of fruit infested with *T. leucotreta* was calculated.

2.5. Data Analysis

Data analyses were performed using R software version 4.2.2 [24]. First, damage level was estimated as the proportion of infested fruits expressed as a percentage of the total number of fruits collected in each farm. The percentage of capsicum fruits with *T. leucotreta* damage symptoms, as well as fruits containing *T. leucotreta* larvae, were arcsine-transformed before analysis. Then, they were subjected to one-way ANOVA followed by Tukey's HSD test to determine statistically significant differences between counties. The effects of climate (temperature, relative humidity, precipitation, and altitude) and cropping system (monocrop and intercrop) on the population of *T. leucotreta* were assessed using the General Linear Model (GLM). Separation of means was performed using the *lsmeans* package [25] with the Tukey *p*-value adjustment method.

Survey data were summarized, and descriptive statistics (means and percentages) were calculated using STATA v14. Those who did not respond to certain questions were excluded from the calculation. Comparative statistical tools such as Chi-square and one-way analysis of variance were used to evaluate the difference in socio-demographic characteristics. In addition, a bivariate probit model was used to determine the effect of socio-demographics on the management option. In cases, where farmers gave more than one reason regarding the given question, percentages were calculated for each group of similar responses.

3. Results

3.1. Occurrence and Density of T. leucotreta

Thaumatotibia leucotreta was present in sampled capsicum farms in the three counties during the survey period of November to December 2021. In Kitui County, *T. leucotreta* was present in 53.6% of the sampled farms, followed by 30% in Machakos County, and in Makueni County, *T. leucotreta* was present in only three farms, representing 12.5% (Figure 2).

The number of farms with *T. leucotreta* were significantly higher in Kitui county compared to other counties (Table 1) ($F = 13.89$, $df = 2, 70$, $p < 0.05$). There was no significant difference between the number of farms with *T. leucotreta* sampled in Machakos and Makueni (Table 1).

Table 1. Number of farms with *T. leucotreta* sampled in Kitui, Machakos, and Makueni Counties.

Counties	No of Farms Visited	No of Farms with *T. leucotreta*
Kitui	28	21.43 ± 0.88 a
Machakos	24	2.50 ± 0.97 b
Makueni	23	3.48 ± 0.82 b

Means within the same column followed by the same letter do not differ significantly (α = 0.05, Turkey's HSD).

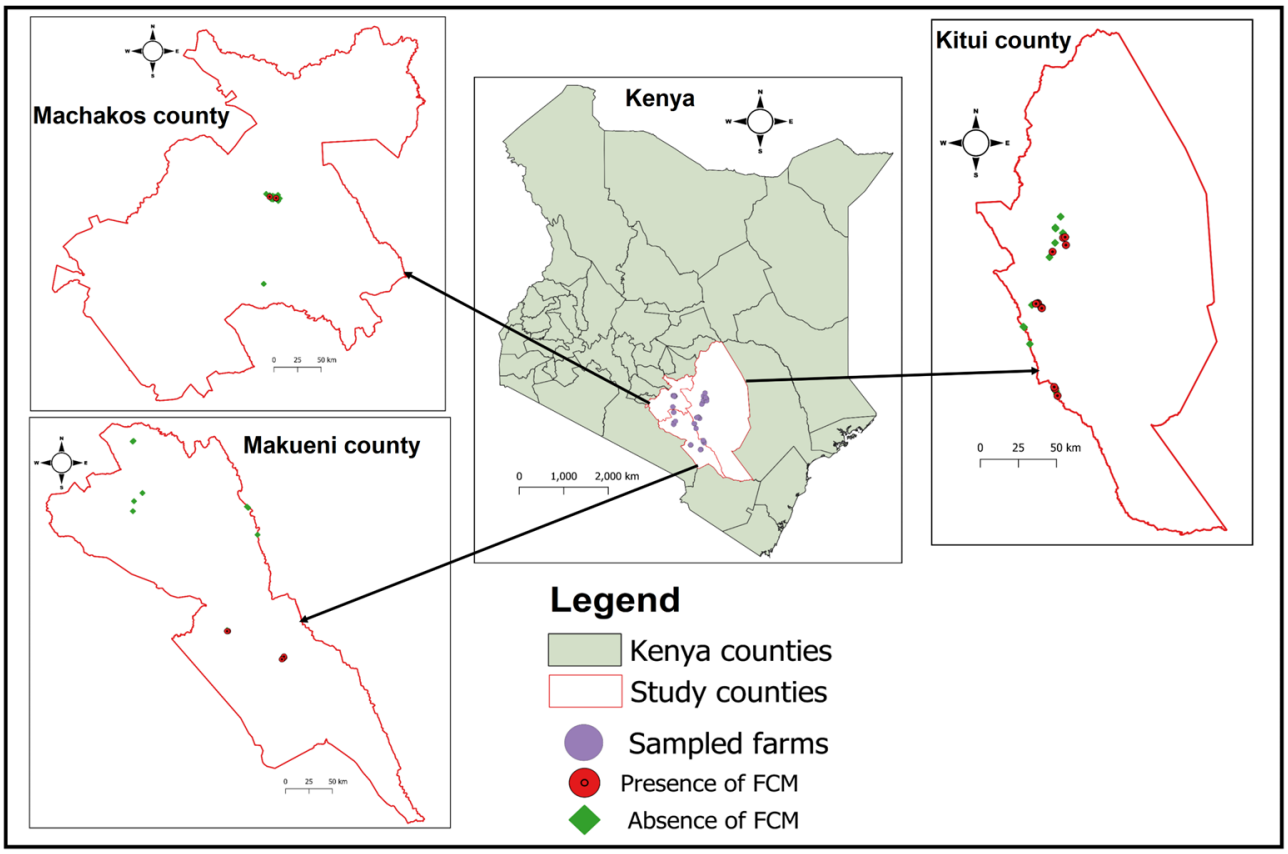

Figure 2. Points where *T. leucotreta* was present in capsicum farms in Kitui, Machakos, and Makueni.

3.2. Effect of Cropping System on T. leucotreta Population

According to the results (LR = 8.502, df = 3, 24, p = 0.0367; Figure 3A) (LR = 8.96, df = 3, 20, p = 0.02978; Figure 3B), the average infestation of *T. leucotreta* was significantly affected by cropping system. In farms that had capsicum intercropped with eggplant in Kitui County, the average infestation of *T. leucotreta* was relatively higher in Kitui as compared to Makueni and Machakos Counties. However, cropping system did not significantly affect the infestation level of *T. leucotreta* in Makueni County (LR = 92.3538, df = 3, 19, p = 0.5023; Figure 3C).

3.3. Damage Level of T. leucotreta on Capsicum in Kitui, Makueni, and Machakos Counties

The damage of *T. leucotreta* on capsicum fruits was significantly higher in Kitui County compared to Machakos and Makueni Counties (F = 12.3, df = 2, 70, $p < 0.001$; (Figure 4)).

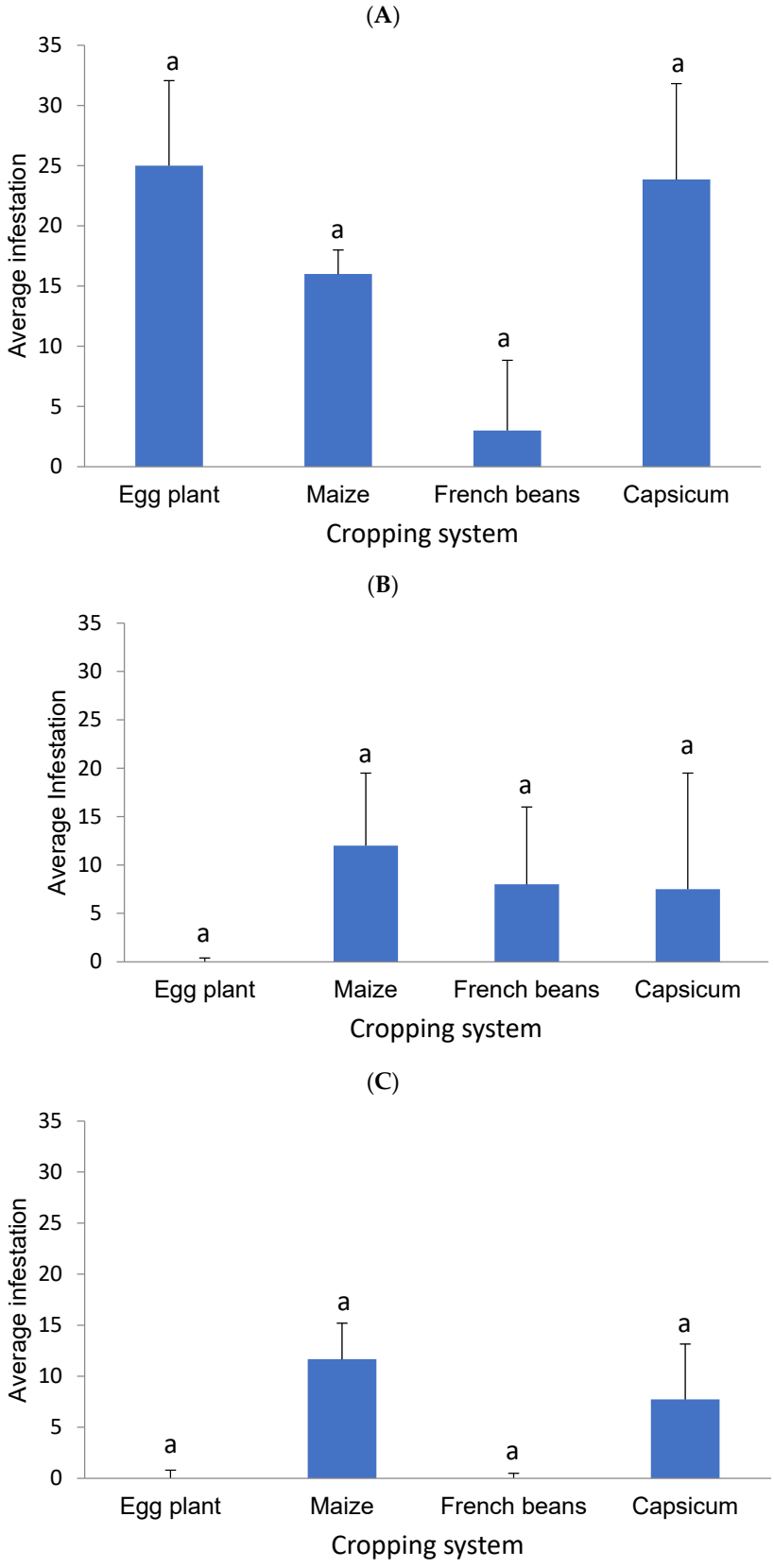

Figure 3. (**A**) Average infestation of *T. leucotreta* in different cropping systems in Kitui County, (**B**) average infestation of *T. leucotreta* in different cropping systems in Makueni County, and (**C**) average infestation of *T. leucotreta* in different cropping system in Machakos County. Bars capped with the same letter are not significantly different ($p = 0.05$, Tukey's HSD).

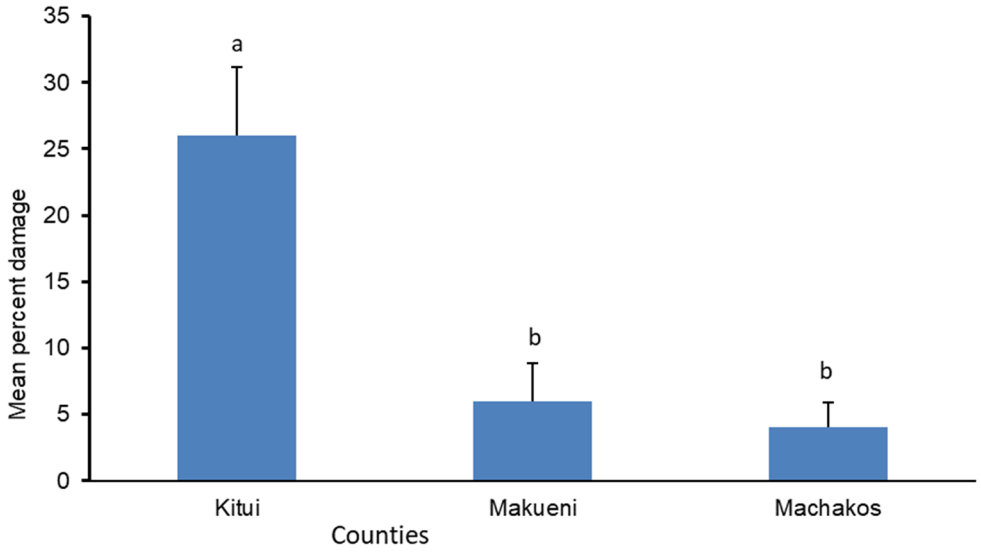

Figure 4. Mean percent damage by *T. leucotreta* on capsicum fruits in three counties. Bars capped with the same letter are not significantly different (p = 0.05, Tukey's HSD).

3.4. Effect of Climate on the Population Density of T. leucotreta in Kitui, Machakos, and Makueni Counties

The generalized linear model showed that the population density of *T. leucotreta* was not significantly affected by the farming system, precipitation, and relative humidity (Table 2). However, temperature and altitude significantly influenced the population density of *T. leucotreta*. An increase in temperature of 1 °C led to a decrease in population abundance of 1.53, while an increase in elevation of 1 m asl led to a decrease in *T. leucotreta* abundance of 0.004 (Table 2).

Table 2. Effect of climate on the population density of *T. leucotreta*.

Variables	Estimates	Z Value	Pr (>|z|)
Intercept	27.3598795	1.533	0.1253
Precipitation	−0.2103881	−1.362	0.1731
Relative humidity	−0.0391787	−0.310	0.7567
Temperature	−1.5319034	−2.082	0.0373 *
Altitude	−0.0044193	−6.977	3.01×10^{-12} ***

*** p-value is less than 0.001; ** p-value is less than 0.01; * p-value is less than 0.05.

3.5. Farmers' Perceptions of the Infestation of T. leucotreta

Survey results indicated that the majority of respondents, 76%, were women. Kitui County had the highest percentage of female respondents (80%) as compared to Makueni (74%) and Machakos (70%). Age ranged from 22 to 73 years with an average of 40.8 years in Machakos, 43 years in Makueni, and 49 years in Kitui. The education level of respondents showed that 42% had attended primary school, 44% secondary school, 10% college, and 3.7% university. The study also showed that 26.7% of respondents ran capsicum enterprises, while 65.2% were engaged in other agricultural jobs, and 8.11% ran non-agricultural enterprises (Table 3).

From the survey, the majority of respondents indicated that pest and disease prevalence was very high in the surveyed region. Apart from false codling moth, thrips were reported to be among the most serious pest of capsicum, with Machakos County leading at (56%) of respondents, followed by Makueni County (43%), and Kitui County (37%). Other pests included red spider mites, whiteflies, aphids, cutworm, and fruit borers (Figure 5A).

Table 3. Socio-economic characteristics of the respondents in surveyed counties.

Variable	County Statistics					
	Machakos (*n* = 41)	**Makueni (*n* = 35)**	**Kitui (*n* = 59)**	**X^2**	***p*-Value**	**Prob > F**
Gender (1 = female, 0 = male) (%)						
Female	71	74.3	79.7	1.0856	0.581	
Male	30.3	25.7	20.3			
Age (years)	40.8	42.7	48.6			0.000 ***
Education (%)						
Primary	34.1	40	47.1	6.2514	0.396	
Secondary	53.6	45.7	37.2			
College	9.7	8.4	14.2			
University	2.4	6.7	0			
Occupation (%)						
Capsicum enterprise	11	22.8	40.6	25.2543	0.000 ***	
Non-agricultural	9	5.6	8.2			
Other agricultural	80	71.6	50.7			

*** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05.

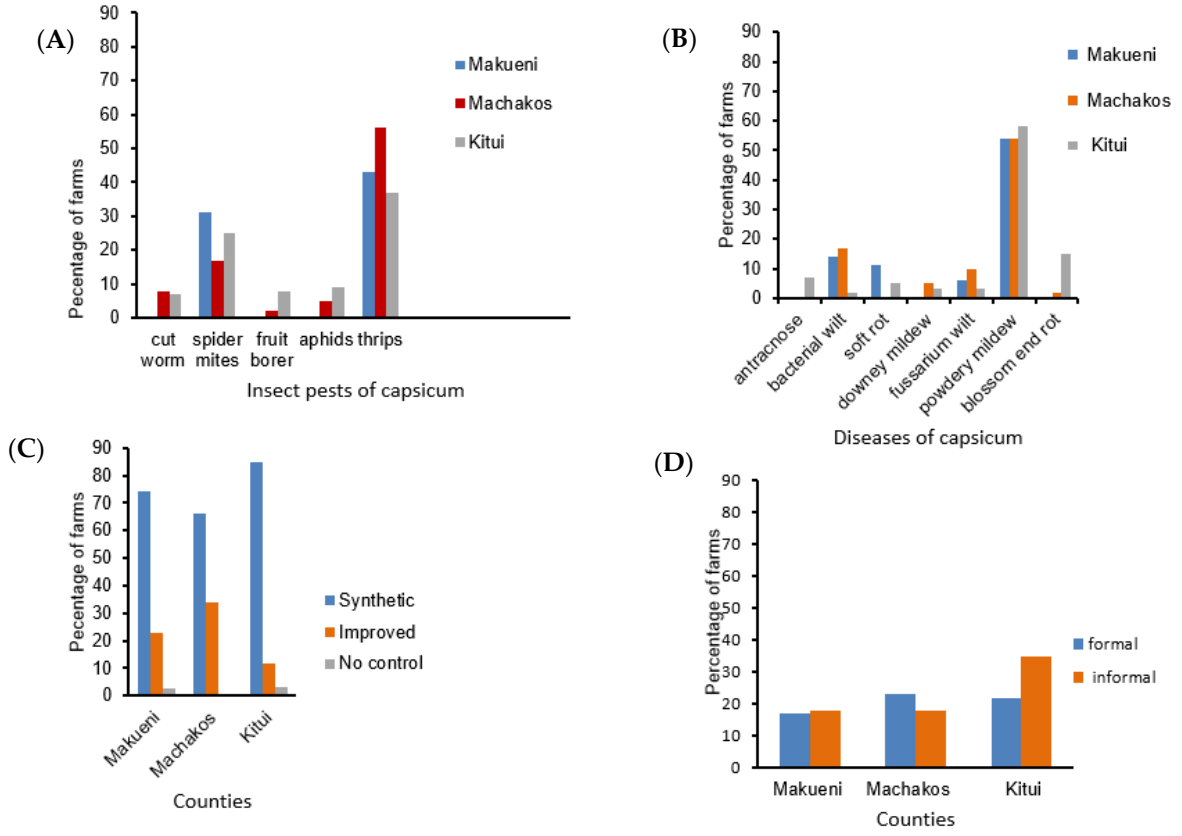

Figure 5. Farming practices that contributed to the occurrence of FCM in surveyed counties. Percentage of other insect pest of capsicum in Kitui, Makueni, and Machakos Counties (**A**), percentage of diseases of capsicum (**B**), percentage of various pest management methods practiced by farmers (pesticide and improved (integrated) pest management methods) (**C**), and (**D**) percentage of seed systems used by farmers to obtain planting material (certified and un-certified seedlings).

Concerning diseases, most farmers (58%) in Kitui County stated that powdery mildew was the main disease that affected the quality and yield of produce in capsicum production, followed by Machakos County (54%) and Makueni County (54%). Other diseases that were

also reported included blossom end rot, fusarium wilt, soft rot, anthracnose, dumping off, bacterial wilt, and downy mildew (Figure 5B).

The application of pesticides is the main method of controlling pests and was reported by 75% of farmers, with Kitui County leading (84%), followed by Makueni County (74%) and Machakos County (66%) (Figure 5C). It was also noted that the majority of farmers (71%) obtained their seeds and seedlings from an informal system (uncertified seeds) with Kitui leading with (35%), followed by Makueni and Machakos Counties (Figure 5D).

The choice of *T. leucotreta* management by the farmers depends on several factors (Table 4). However, the occupation of the farmer and access to credit were the most important factors contributing to the choice of management method used to control *T. leucotreta* (Table 4).

Table 4. Socio-economic factors influencing the choice of *T. leucotreta* management method.

Improved Method (Integrated Pest Management)				
Variable	**Coef**	**Std. Err**	**t**	**Robust Std. Err**
Gender (1 = female, 0 = male) (%)				
Female	0.2996021	0.94	0. 347	0.3185232
Age (years)	−0.0136649	−1.29	0.197	0.0105849
Education (%)				
Secondary	0.0496152	0.19	0.852	0.2661753
College	0.0120188	0.03	0.978	0.4392452
University	0.0289602	−0.04	0.965	0.6661017
Occupation (%)				
Capsicum enterprise	5.154779	−21.13	0.000 ***	0.243956
Non-agricultural	5.265498	−11.23	0.000 ***	0.04690484
Other agricultural	5.325987	−36.17	0.000 ***	0.1472311
Credit access	4.981223	−34.30	0.000 ***	0.1452083

*** *p*-value is less than 0.001; ** *p*-value is less than 0.01; * *p*-value is less than 0.05.

4. Discussion

Though FCM has been reported in many African countries, information on its occurrence, abundance, and distribution in the different hosts and geographical areas is limited. This knowledge is important when enforcing regulations on phytosanitary measures at the national level [3]. The study also provides an important insight on farmers' perception of *T. leucotreta*, pest management, and other agricultural practices of farmers in this region, since they varied from county to county. In the present study, *T. leucotreta* was detected in all the surveyed counties in Lower Eastern Kenya. The pest population was higher in Kitui County compared to Machakos and Makueni Counties. A significantly higher percentage of damaged fruits, as well as higher larval density, was recorded in Kitui County than in Machakos and Makueni Counties. This could be attributed to differences in biotic factors such as outbreaks of other pests and diseases, as well as farming practices carried out by farmers (excessive use of pesticides, uncertified seeds, and poor cropping systems) [3].

It was evident that cropping system significantly affected *T. leucotreta* population in Kitui and Machakos Counties; however, it did not significantly affect *T. leucotreta* population in Makueni County. The average infestation of *T. leucotreta* in capsicum farms in Kitui County that were intercropped with eggplant was relatively higher as compared to farms that were intercropped with maize, French beans, and those with capsicum only (not intercropped with any other crop). In Makueni and Machakos Counties, farms where capsicum was not intercropped with any crop and farms where capsicum was intercropped with maize had a relatively higher average infestation of *T. leucotreta* compared to the other two types of farms. Previous studies have shown that monocropping practices with one planting season overlapping with another throughout the year and warm humid

conditions promote population builds, allowing several generations to overlap with a single crop cycle with suitable prevailing conditions. Consequently, *T. leucotreta* can remain active throughout the year if the correct host is present; this may be responsible for the higher pest population observed in capsicum farms in this county [6,26,27]. FCM is a polyphagous pest with an extensive host range including capsicum, eggplant, and maize among others [4,6]; therefore, intercropping capsicum with these crops may modify the microclimate to favor the multiplication of this pest, thereby creating more problems in capsicum growing areas [26].

The results found that temperature and altitude significantly influenced the population density of *T. leucotreta* such that any increase in temperature led to a slight decrease in the pest population, while an increase in elevation led to a decrease in *T. leucotreta* abundance. This is because higher altitudes are characterized by harsh climatic conditions, such as low temperature and moisture, limited food resources, and habitat constraints, and thus less suitable for herbivores [28]. Previous studies have shown that temperature influences various aspects of insect biology, such as sex ratio, adult life span, survival, fecundity, and fertility [29]. As a result, temperature profoundly affects colonization, distribution, abundance, behavior, life history, and fitness of insects [30].

Insect pest infestation and disease prevalence were very high in the surveyed region. Apart from FCM, other pests and diseases that were identified to cause serious damage to capsicum fruit included the diseases blossom end rot, soft rot, and anthracnose; the insect pests various caterpillars, fruit borers, and aphids; and birds. Any injury to fruit as a result of pests and diseases can attract *T. leucotreta* to oviposit on the fruit as well as make it easier for the larvae to penetrate the fruit [31].

The highest percentage of farmers who were interviewed in Kitui County depended on pesticides for pest management. The majority used broad spectrum insecticides, with only a few using Bt and other bio-control methods such as Lures. Some of the insecticides that were mainly used by farmers to control *T. leuctreta* included: Benocap (Indoxicarb 85 g/L + Emamectin Benzoate 15 g/L), Pyrethrin (cinerin I and II and jasmolin I), and Luferon (milbemycin oxime/lufenuron (Sentinel), among others. Other pesticides used included Acoster (abamectin-aminomethyl 50 g/L), Abamectin (80% avermectin B1a and 20% avermectin B1b), and Escort (metsulfuron methyl), among others. Despite the use of pesticides in Kitui County, higher *T. leucotreta* infestation and damage level was observed. This is because the majority of farmers applied insecticides when high damage had already been inflicted by FCM, as most farmers apply pesticide after noticing plant damage; or some of the pesticides being used may not be the right ones; their doses and concentrations may not be optimal; or may be applied at the wrong age of plant growth, which was frequently observed in farmers' fields. This renders the chemicals ineffective, inconsistent, and unsatisfactory in terms of controlling pests in a given local context [32]. Chemical pesticides are often relatively inexpensive and highly effective, resulting in side effects.. As a solution to the increase in pest infestation, the majority of farmers are prompted to spray excessively, which eventually leads to insecticide resistance [33]. Excessive use of broad-spectrum pesticides increases pest incidence as a result of insects developing resistance to certain pesticides [19]. Pesticides also have detrimental effects on predators, parasites, and pathogenic organisms which control the targeted pests, which may result in pest resurgence [19].

The number of pesticide application was correlated to gender, age, and level of education. Women are known to take leadership roles in pesticide application in some developing countries; however, in this study, pesticides were mainly applied by men. This is because women had knowledge of the possible negative effects of pesticide use, as well as alternative pest control measures and beneficial insects, despite their ability to observe the change in prevalence of pests [34]. The study found that age was negatively associated with the probability of choosing integrated pest management methods. This is because aging farmers are most likely to not exhibit the zeal and interest required to promote and popularize new innovations [35].

Education level had a positive effect on the probability of adopting integrated pest management adoption. This result is similar to the results of a number of studies that have indicated that the level of education influences the adoption of agricultural technologies [36,37] due to being well-informed about crop diversification and the balanced use of land in order to minimize risks [38]. Farmers with IPM experience considered the environmental criteria in their choice and use of pesticides as compared to those farmers who lacked any IPM experience, and farmers who faced health risks related to working with pesticides showed a tendency to prefer environmental criteria when using pesticides compared to those farmers who did not have such experience [39]. It is believed that access to credit promotes the adoption of risky technologies through relaxation of the liquidity constraint, as well as through the boosting of a household's risk-bearing ability [40].

It is also evident that the majority of farmers in Kitui County sourced their planting material from informal sources, such as seedlings from nurseries that were not certified, while others used their seedlings and were not assured of the cleanliness of the planting material. Seed quality is affected by many aspects of production, such as seed source, production practices, management, and cropping systems [41]. Low-quality seeds result in defective seedlings, reduced crop stand, low crop establishment, and infection with pests and diseases in the field [42].

5. Conclusions

The results from this study have demonstrated that FCM has established itself across the sampled counties in Lower Eastern Kenya. False codling moth infestation and damage was demonstrated to be higher in Kitui County as compared to Makueni and Machakos Counties. This is a threat to the export market, as well as food security for farmers depending on capsicum production for sustenance. Farming practices such as crop production and pest management negatively influenced FCM infestation and damaged the capsicum agro-ecosystem in the sampled areas. The study recommends the incorporation of good cropping systems as well as proper selection of clean capsicum seedlings by the use of certified seeds for sustainable FCM management, especially in smallholder farming. Training and awareness regarding the application and knowledge of chemical control products for small-scale farmers is necessary. It is also important to note that excessive use of similar active ingredients may lead to resistance in the target pest. The majority of farmers did not apply the preventive measures and management activities against false codling moths as recommended due to lack of knowledge. Therefore, there is a need for an adequate awareness program to enhance the knowledge of farmers. Health education is crucial and should be strengthened, especially where there is an alert on the outbreak of pests, since this is the time most farmers are likely to spray and come into contact with chemicals.

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References

1. Carpenter, J.; Bloem, S.; Hofmeyr, H. Area-wide control tactics for the false codling moth *Thaumatotibia leucotreta* in South Africa: A potential invasive species. In *Area-Wide Control of Insect Pests: From Research to Field Implementation*; Springer: Dordrecht, The Netherlands, 2007; pp. 351–359. [CrossRef]
2. Gilligan, T.M.; Epstein, M.E.; Hoffman, K.M. Discovery of false codling moth, *Thaumatotibia leucotreta* (Meyrick), in California (*Lepidoptera: Tortricidae*). *Proc. Entomol. Soc. Wash.* **2011**, *113*, 426–435. [CrossRef]
3. Adom, M.; Fening, K.O.; Billah, M.K.; Wilson, D.D.; Hevi, W.; Clottey, V.A.; Ansah-Amprofi, F.; Bruce, A.Y. Pest status, bio-ecology and management of the false codling moth, *Thaumatotibia leucotreta* (*Meyrick*) (*Lepidoptera: Tortricidae*) and its implication for international trade. *Bull. Entomol. Res.* **2000**, *111*, 17–30. [CrossRef] [PubMed]
4. Venette, R.C.; Davis, E.E.; Dacosta, M.; Heisler, H.; Larson, M. *Mini Risk Assessment False Codling Moth*; CAPS PRA, Department of Entomology, University of Minnesota: St. Paul, MN, USA, 2003; pp. 1–30.
5. Love, C.N. The Biology, Behaviour and Survival of Pupating False Codling Moth, *Thaumatotibia leucotreta* (*Meyrick*) (*Lepidoptera: Tortricidae*), a Citrus Pest in South Africa. Master's Thesis, Rhodes University, Grahamstown, South Africa, 2015.
6. De Jager, Z.M. Biology and Ecology of the False Codling Moth, *Thaumatotibia leucotreta* (*Meyrick*). Ph.D. Thesis, Stellenbosch University Zoë, Cape Town, South Africa, 2013. Available online: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=e258e4854bdb2a6bcd01100850a3a2ca54cfaf95 (accessed on 7 February 2023).
7. Moore, S.D. Biological Control of a Phytosanitary Pest (*Thaumatotibia leucotreta*): A Case Study. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1198. [CrossRef] [PubMed]
8. Mazza, G.; Strangi, A.; Marianelli, L.; Del Nista, D.; Roversi, P.F. *Thaumatotibia leucotreta* (*Meyrick*) (*Lepidoptera Tortricidae*) intercepted for the first time in Italy. *J. Zool.* **2014**, *97*, 147–149.
9. Lagiso, D.; Geta, E. Technical Efficiency of Red Pepper Production: The Case of Dalocha, Southern Ethiopia. *Asian J. Agric. Ext. Econ. Sociol.* **2019**, *37*, 1–8. [CrossRef]
10. Adetula, A.O.; Olakojo, S.A. Genetic Characterization and Evaluation of Some Pepper Accessions *Capsicum frutescens* (L.): The Nigerian 'Shombo' Collections. *J. Agric. Environ. Sci.* **2006**, *1*, 273–281.
11. Ocharo, E.N.; Korir, K.N.; Gweyi-Onyango, J. Integration of mulching and row spacing on weed management in Green Pepper varieties. *Soc. Trop. Plant Res.* **2017**, *4*, 203–209. [CrossRef]
12. Carrizo García, C.; Barfuss, M.H.J.; Sehr, E.M.; Barboza, G.E.; Samuel, R.; Moscone, E.A.; Ehrendorfer, F. Phylogenetic Relationships, Diversification and Expansion of Chili Peppers (*Capsicum*, Solanaceae). *Ann. Bot.* **2016**, *118*, 35–51. [CrossRef]
13. Nguyen, N.G.; Lantzke, N. Mitigating the Adverse Effects of Semi-Arid Climate on Capsicum Cultivation by Using the Retractable Roof Production System. *Plants* **2022**, *11*, 2794. [CrossRef]
14. Bunde, M.A.; Omami, E.N.; Mutui, T.M.; Opala, P.; Angima, R.O. Influence of Plant Density and Nitrogen Application on Growth and Quality of Sweet Pepper (*Capsicum annuum*) in Uasin Gishu County. *Int. J. Recent Sci. Res.* **2021**, *12*, 40614–40619. [CrossRef]
15. Malan, A.P.; Diest, J.I.V.; Moore, S.D.; Addison, P. Control Options for False Codling Moth, *Thaumatotibia leucotreta* (*Lepidoptera: Tortricidae*), in South Africa, with Emphasis on the Potential Use of Entomopathogenic Nematodes and Fungi. *Afr. Entomol.* **2018**, *26*, 14–29. [CrossRef]
16. Patrick, M.E.; Koomen, I.; Ndlela, S.; Wesonga, M.J. Efect of Moisture Stress on the Development of False Codling Moth *Thaumatotibia leucotreta* (*Lepidoptera: Tortricidae*) on Two Tomato Varieties. *Neotrop. Entomol.* **2021**, *50*, 828–834. [CrossRef] [PubMed]
17. Floriculture. Kenyan Pepper Threatened by Pest. 2015. Available online: http://www.forinews.com/index.php/past-featured-articles/50-featured-articlejuly-august-2015/170-kenyan-pepper-threatened-by-pest (accessed on 18 May 2021).
18. Onah, I.E.; Taylor, D.; Eyo, J.E.; Ubachukwu, P.O. Identification of the False Codling Moth, *Thaumatotibia leucotreta* (*Meyrick*) (*Lepidoptera: Tortricidae*), Infesting Sweet Oranges in Nigeria, by DNA Barcoding. *Proc. Entomol. Soc. Wash.* **2016**, *118*, 574–581. [CrossRef]
19. Mkiga, A.M.; Mohamed, S.A.; Du Plessis, H.; Khamis, F.M.; Ekesi, S. Field and laboratory performance of false codling moth, *Thaumatotibia leucotreta (Lepidoptera: Troticidae*) on orange and selected vegetables. *Insects* **2019**, *10*, 63. [CrossRef]
20. Amukono, C.L.; Bosire, E.; Lukorito, C. Agro Climatic Characterization of Makueni County Using Rainfall Data. Bachelor's Thesis, University of Nairobi, Nairobi, Kenya, 2016.

21. Huho, J.M. An analysis of rainfall characteristics in Machakos County, Kenya. *IOSR J. Environ. Sci. Toxicol. Food Technol.* **2017**, *11*, 64–72. [CrossRef]
22. Kichamu, E.A.; Ziro, J.S.; Palaniappan, G.; Ross, H. Climate change perceptions and adaptations of smallholder farmers in Eastern Kenya. *Environ. Dev. Sustain.* **2017**, *20*, 2663–2680. [CrossRef]
23. Opoku-Debrah, J.K.; Hill, M.P.; Knox, C.; Moore, S.D. Comparison of the biology of geographically distinct populations of the citrus pest, *Thaumatotibia leucotreta* (Meyrick) (*Lepidoptera*: *Tortricidae*), in South Africa. *Afr. Entomol.* **2014**, *22*, 530–537. [CrossRef]
24. R Development Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2020.
25. Lenth, R.V. lsmeans: Least-squares means. The R package version 2.30–0. *J. Stat. Softw.* **2015**, *69*, 1–33. [CrossRef]
26. Waweru, B.W.; Kilalo, D.C.; Miano, D.W.; Kimenju, J.W.; Rukundo, P. Diversity and economic importance of viral diseases of pepper (*Capsicum* spp.) in Eastern Africa. *J. Appl. Hortic.* **2019**, *21*, 70–76. [CrossRef]
27. Buteme, S.; Masanza, M.; Masika, F.B. Severity and prevalence of the destructive fall armyworm on maize in Uganda: A case of Bulambuli District. *Afr. J. Agric. Res.* **2020**, *16*, 777–784. [CrossRef]
28. Dostálek, T.; Rokaya, M.B.; Münzbergová, Z. Altitude, habitat type and herbivore damage interact in their effects on plant population dynamics. *PLoS ONE* **2018**, *13*, e0209149. [CrossRef] [PubMed]
29. Bashir, A.M.; Batoo, M.; Khan, H.; Shahid Nisar, S.M.; Farooq, H.; Mohamed Hashem, M.; Alamri, S.; El-Zohri, A.M.; Alajmi, A.R.; Tahir, M.; et al. Effect of temperature & humdity on population dynamics of insects' pest complex of cotton crop. *PLoS ONE* **2022**, *17*, e0263260. [CrossRef]
30. Ju, R.T.; Wang, F.; Li, B. Effects of temperature on the development and population growth of the sycamore lace bug, Corythucha ciliata. *J. Insect Sci.* **2011**, *11*, 16. [CrossRef] [PubMed]
31. Moore, S.D. The Development and Evaluation of *Cryptophlebia Leucotreta* Granulovirus (Crlegv) as a Biological Control Agent for the Management of False Codling Moth, *Cryptophlebia Leucotreta*, on Citrus. Ph.D. Thesis, Rhodes University, Grahamstown, South Africa, 2002.
32. Korir, J.K. Factors influencing intensity of adoption of integrated management package and pesticide misuse in the control of mango fruit fly in Embu East Sub-county, Kenya. In *Research in Agricultural & Applied Economics*; University of Nairobi: Nairobi, Kenya, 2016.
33. Daniel, C.A. Improving the Cold Tolerance of False Codling Moth, *Thaumatotibia Leucotreta*, for Better Performance in a Sterile Insect Release Programme (Issue June). Master's Thesis, Rhodes University, Grahamstown, South Africa, 2016.
34. Mwadzingeni, L.; Mugandani, R.; Mafongoya, P.L. Gendered perception of change in prevalence of pests and management in Zimbabwe smallholder irrigation schemes. *Agron. Sustain. Dev.* **2022**, *42*, 90. [CrossRef]
35. Ofuoku, A.U.; Egho, E.O.; Enujeke, E.C. Integrated Pest Management (IPM)Adoption among Farmers in Central Agro-Ecological Zone of Delta State, Nigeria. *Adv. Biol. Res.* **2009**, *3*, 29–33.
36. Sofoluwe, N.A.; Tijani, A.A.; Kareem, R.O. Socio-economic factors influencing the use of botanicals in cocoa pest management. *Thai J. Agric. Sci.* **2013**, *46*, 29–35.
37. Mlenga, D.H. Factors Influencing Adoption of Conservation Agriculture: A Case for Increasing Resilience to Climate Change and Variability in Swaziland. *J. Environ. Earth Sci.* **2015**, *5*, 16–25.
38. Mal, P.; Anik, A.R.; Bauer, S.; Schmitz, P.M. Bt cotton adoption: A double-hurdle approach for North Indian Farmers. *Ag BioForum* **2012**, *15*, 294–302.
39. Sharifzadeh, M.S.; Abdollahzadeh, G.; Damalas, C.A.; Rezaei, R. Farmers' criteria for pesticide selection and use in the pest control process. *Agriculture* **2018**, *8*, 24. [CrossRef]
40. Mwangi, M.; Kariuki, S. Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *J. Econ. Sustain. Dev.* **2015**, *6*, 208–216.
41. Njonjo, M.W. Quality of Cowpea Seed Used by Farmers in Makueni and Taita Taveta Counties and Its Effect on Crop Performance. Ph.D. Thesis, University of Nairobi, Nairobi, Kenya, 2018; pp. 1–29.
42. Mutundi, A.N.; Muthomi, J.W.; Olubayo, F.M.; Leley, P.K.; Nzuve, F.M. Effect of Farm Saved Maize (*Zea mays L.*) Seed on Intensity of Foliage Diseases. *J. Agric. Sci.* **2019**, *11*, 45. [CrossRef]

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