



Incidence, Severity, and Species Distribution of Fruit Flies in Relation to Agroecological and Environmental Factors in Sierra Leone

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Abstract: Fruit flies (Diptera: Tephritidae) are major constraints to tropical fruit production, threatening food security and export markets. However, empirical data on their diversity and infestation dynamics in Sierra Leone's mango systems remain limited. This study assessed fruit fly incidence, severity, and species composition across agroecological zones to inform integrated pest management (IPM) and phytosanitary strategies. Field surveys were conducted from June to December in eight mango orchards across Moyamba, Tonkolili, and Koinadugu districts. Populations were monitored weekly using McPhail traps baited with methyl eugenol, cue lure, trimedlure, and terpinyl acetate. Specimens were identified morphologically, while infestation severity was quantified as flies-per-trap-per-day (FTD). Diversity indices (Shannon-Wiener, Simpson, and Pielou's evenness) and statistical models (ANOVA, GLMM) were applied to evaluate spatial, temporal, and phenological effects. The results revealed that a total of 5,947 flies were recorded, dominated by *Bactrocera dorsalis* (74.5%), followed by *Zeugodacus cucurbitae* (15.1%), with *Ceratitis* spp. occurring at lower frequencies. Tonkolili exhibited the highest abundance and diversity ($H' = 1.45$), whereas Moyamba showed reduced diversity ($H' = 0.40$). Methyl eugenol was the most effective attractant ($\chi^2 = 89.34$, $p < 0.001$). Fruit fly populations varied significantly with season and crop phenology, peaking during the vegetative stage and in October (incidence 12.4%; severity index 9.23 ± 0.89), before declining toward December. The findings identify *B. dorsalis* as the dominant pest, with infestation patterns shaped by agroecological conditions, lure efficacy, and phenology. Targeted deployment of methyl eugenol traps, coupled with seasonal surveillance and strengthened phytosanitary practices, is recommended to enhance sustainable fruit fly management in Sierra Leone.

Keywords: Tephritidae fruit flies, Fruit fly diversity, *Bactrocera dorsalis*, Mango (*Mangifera indica*), Integrated pest management (IPM), Phytosanitary measures, Agroecological variation

INTRODUCTION

Fruit flies (Diptera: Tephritidae) constitute one of the most economically important groups of insect pests affecting fruit production worldwide, with particularly severe impacts in tropical and subtropical regions. Globally, approximately 4,000 species have been identified within the family Tephritidae, of which about 350 are considered economically significant [1]. These pests cause direct damage to fruits and vegetables through oviposition and larval feeding, leading to yield losses that may reach 90-100% depending on environmental and host conditions [1]. Beyond production losses, fruit fly infestations also result in major economic consequences through reduced market value and restricted export opportunities due to strict quarantine regulations [2]. In West Africa, studies have shown high diversity

and widespread distribution of fruit fly species across ecological zones. A baseline study in Togo identified 40 species in mango orchards using parapheromone-based trapping systems, with dominant species including *Bactrocera dorsalis*, *Ceratitis cosyra*, *Ceratitis fasciventris*, *Ceratitis capitata*, and *Zeugodacus cucurbitae* [3]. Similarly, research in Burkina Faso documented 29 species across multiple agroecological systems, including several new national records, highlighting the region's underexplored fruit fly diversity [4].

Fruits and vegetables are essential for human nutrition, providing vitamins, minerals, and dietary fiber [5]. Increased awareness of their health benefits has driven rising demand in West Africa [6], where consumption is associated with reduced risk of chronic diseases [7-9]. In response, horticultural production has expanded significantly over recent decades [10]. In Sierra Leone, mango (*Mangifera indica* L.) plays an important socio-economic role in employment and income generation [11], yet fruit fly infestation remains a major constraint to productivity and trade. Despite this importance, limited information exists on fruit fly diversity and distribution in the country. Therefore, this study aims to assess fruit fly diversity and prevalence in Sierra Leone to support effective pest management strategies.

MATERIALS AND METHODS

Study Area

This study was conducted in three major mango-producing districts of Sierra Leone: Moyamba District in the southern region, and Tonkolili District and Koinadugu District in the northern region. These districts represent distinct agroecological zones, providing a gradient of climatic and environmental conditions suitable for assessing fruit fly distribution, incidence, and severity. Moyamba District experiences a tropical monsoon climate (Am) with a prolonged rainy season from May to October and a short dry season from November to April. Annual rainfall ranges from approximately 1,600 to 2,500 mm, peaking in August, while temperatures remain high year-round (~27-37 °C) with relative humidity often exceeding 90% during the wet season. The district's forest-savanna mosaic and lowland rainforest vegetation provide favorable conditions for mango cultivation and support the proliferation of fruit fly populations.

Tonkolili District, located inland in the Sudano-Guinean transitional zone, also exhibits a tropical monsoon climate with distinct wet and dry seasons. Rainfall averages 1,400-1,500 mm annually, with the heaviest rains in July and August, and dry-season precipitation as low as 3-4 mm. Temperatures are consistently high (~27-38 °C) with relative humidity ranging from ~58% in the dry season to >90% in the wet season. The district is dominated by derived savanna and woodland interspersed with agroforestry systems, which influence cropping patterns and pest distribution. Koinadugu District, in the northern highlands, has a tropical wet-and-dry (savanna) climate with a pronounced wet season (May-October) and dry season (November-April). Annual rainfall ranges from ~1,200-1,300 mm, peaking in August. Daytime temperatures are high (~20-36 °C), with cooler nights due to elevation. Relative humidity varies widely, from ~38% in the dry season to over 90% in peak rains. Vegetation consists of montane savanna and gallery forests, with upland agricultural systems shaped by seasonal rainfall and altitude, which may influence fruit fly species composition and abundance.

Orchard Selection and Description

A total of eight mango orchards were purposively selected across the three districts based on criteria including orchard size, age, varietal composition, and the absence of routine phytosanitary control practices. The selected orchards were coded as follows: SL1V3 and SL1V6 in Moyamba District; SL1V3, SL1V4, SL1V5, SL1V6, and SL1V8 in Tonkolili District; and SL1V5 in Koinadugu District. The orchards comprised commonly cultivated mango varieties, including Sheep Tone, Big Cherry, Common, Kerosene, and Rope Rope, reflecting the diversity of local germplasm and farmer preferences. These orchards represent typical smallholder mango production systems in Sierra Leone and were selected to capture variability in fruit fly infestation across ecological zones. Field data collection was conducted from June to December, encompassing the major mango fruiting and harvesting period, as well as peak fruit fly activity associated with favorable climatic conditions.

Fruit Fly Trapping Design and Installation

Fruit fly populations were monitored using standard trapping protocols based on internationally recognized procedures[12]. In each orchard, a central mango tree was identified, and four additional trees were selected around it to form a rhombus-shaped sampling layout with approximately 100 m spacing to ensure spatial coverage. A total of sixteen traps were installed per orchard using McPhail-type (Tephri Trap) monitoring devices. Each trap was baited with a specific male parapheromone to target different fruit fly genera, including methyl eugenol (ME) for *Bactrocera* species, cue lure (CUE) for *Dacus* and *Zeugodacus* species, trimedlure (TM) for *Ceratitis* species, and terpinyl acetate (TA) for additional *Ceratitis* species. Traps were suspended under the tree canopy at approximately 2 m above ground level to ensure shading and optimal capture efficiency. An organophosphate insecticide (dichlorvos, DDVP) was added to each trap to kill captured insects. Parapheromones were replaced every six weeks, while the insecticide was renewed every two months to maintain trapping efficiency throughout the study period.

Sampling and Data Collection

Traps were inspected on a weekly basis, and captured fruit flies were collected, counted, and preserved in 70% ethanol for laboratory identification. Data was recorded for each trap, orchard, and sampling date.

The parameters assessed included species composition, abundance, incidence, and severity of infestation. Incidence was determined as the presence or absence of fruit fly species within each orchard, while severity was quantified using fly density per trap per day (FTD), calculated as:

$$FTD = \frac{\text{Total number of flies captured}}{\text{Number of traps} \times \text{Number of days}}$$

Identification of Fruit Fly Species

The Tephritidae captured by each trap was sorted and identified per district before taken to the Fruit flies Taxonomy Lab at the Crop Protection Department, School of Agriculture

and Food Sciences, Njala University, Njala Campus. Kori Chiefdom, Southern Province of Sierra Leone, in order to be able to identify the different species found in a particular district using the dichotomous keys[13-15] and identification key leaflets of the main fruit fly species in West Africa, provided by the PLMF. Also, comparisons with the reference collection of Tephritidae from LEA (samples of host species was confirmed by the ECOWAS COMMISSION against Fruit fly in Burkina Faso. According to IAEA [12] applied in the case where no control measures were taken in the orchards.

Classification of Infestation Levels

Fruit fly infestation levels were categorized based on FTD thresholds following international standards:

- $FTD > 1$: High infestation requiring full phytosanitary intervention
- $0.1 \leq FTD \leq 1$: Moderate infestation requiring suppression measures
- $FTD < 0.1$: Low infestation indicating near-eradication conditions
- $FTD = 0$: Pest-free status requiring exclusion measures

Statistical Analysis

All statistical analyses were performed using R statistical software. Analysis of variance (ANOVA) was conducted to compare fruit fly abundance across districts and orchards. Where significant differences were observed, means were separated using the Student-Newman-Keuls test at a 5% significance level. Descriptive statistics, including means, standard deviations, and percentages, were computed to summarize fruit fly populations. Spatial variation in fruit fly distribution was also assessed to identify patterns of infestation across agroecological zones. Within-orchard species diversity (alpha diversity) was assessed using species richness (S), Shannon-Wiener diversity index (H'), Simpson diversity index (D), and Pielou's evenness index (E). These indices provide measures of species abundance, dominance, and distribution uniformity within each orchard.

RESULTS AND DISCUSSION

Distribution and Incidence of Fruit Fly Populations Across Sampled Orchards and Districts

The results on the abundance of fruit fly revealed significant variation across districts and orchard (Table 1). The highest capture was recorded in Tonkolili district particularly in orchard SL1V3 (2,800 flies). Similarly, the corresponding alpha diversity indices (Table 2) further revealed the same pattern with highest Shannon diversity ($H' = 1.45$) observed in the same orchard. The results also revealed moderate abundance levels in Koinadugu district and in orchard SL1V5 (834) with intermediate diversity ($H' = 1.10$), while low-abundance orchards in Moyamba (SLV6) exhibited reduced diversity ($H' = 0.40$). It also observed that in Orchard SL1V6 in Tonkolili, no fruits flies were captured thus no diversity was recorded. The evenness values recorded were generally high in orchards with greater abundance indicating that a relatively uniform distribution of species but decline in low density sites

Table 1: Distribution and Incidence of Fruit Fly Populations Across Sampled Orchards and Districts

Orchard Code	District	Total Fruit flies captured	Mean Fruit flies per trap	Incidence rate	95% CI(Lower)	95% CI(Upper)
SL1V3	Moyamba	1,132	32.3	6.79	6.41	7.19
SL1V3	Tonkolili	2,800	50.0	16.80	16.20	17.41
SL1V4	Tonkolili	200	14.3	1.20	1.04	1.38
SL1V5	Koinadugu	834	15.2	5.00	4.67	5.35
SL1V5	Tonkolili	65	21.7	0.39	0.31	0.50
SL1V6	Moyamba	97	3.2	0.58	0.48	0.71
SL1V6	Tonkolili	480	32.0	2.88	2.63	3.15
SL1V8	Tonkolili	0	0.0	0.00	0.00	0.22

Table 2: Alpha Diversity Index of Tephritidae in Sampled Orchards

Orchard Code	Simpson Index (D)	Shannon Index (H')	Hmax	Pielou Evenness (E)
SL1V3 (Moyamba)	0.82	1.25	1.39	0.90
SL1V3 (Tonkolili)	0.95	1.45	1.61	0.90
SL1V4 (Tonkolili)	0.55	0.80	1.10	0.73
SL1V5 (Koinadugu)	0.78	1.10	1.39	0.79
SL1V5 (Tonkolili)	0.40	0.65	1.10	0.59
SL1V6 (Moyamba)	0.22	0.40	1.10	0.36
SL1V6 (Tonkolili)	0.70	1.05	1.39	0.76
SL1V8 (Tonkolili)	0.00	0.00	0.00	0.00

Species Composition, Relative Abundance, and Estimated Damage Potential of Fruit Flies

The results in Table 3 showed species composition across the study studies and orchard with some species dominating in all orchards. In total 5,947 flies were recorded during the evaluation with clear variation in their abundance and their potential to cause damage. The results revealed that among all the species observed, *Bactrcera dorsalis* was the most dominant with a relative abundance of 75.4(74.5%) of the total catch followed by *Zeugodacus cucurbitae* with a relatic abundance of 15.1(15.1%). Other species including *Ceratitis capitata* and *Ceratitis cosyra* were observed in much smaller portion with a relative abundance less than 3.0(3%) while other *Ceratitis species* recorded relative abundance of 4.2% and unidentified *Bactrocera species* were observed in a very small portion with a low relative abundance of 0.5 The results on potential damage indicate slightly different pattern with *Bactrcera dorsalis* recording lower damage weight(1.0). However, even though *Bactrcera dorsalis* has lower damage weight but records higher relative damage potential indicating that its high population can still contribute to nearly half(49.6%) of the total potential damage. On the other hand, *Z. cucurbitae* contributed 15.0% to the total damage potential. Its higher damage weight increased its importance, even though its population was smaller. Similarly, *Ceratitis capitata* and *Ceratitis cosyra*, despite their low numbers, still contributed noticeable damage due to their higher damage weights. Other *Ceratitis species* also showed a moderate contribution. It can be seen from the results that findings that fruit fly infestation in the study areas is largely driven by *B. dorsalis*, with *Z. cucurbitae* acting as an important secondary pest, and *Ceratitis species* contributing at lower but still relevant levels.

Table 3: Species composition, relative abundance, and estimated damage potential of fruit flies in the study area

Species	Total count	Relative abundance	95% CI	Damage weight	Weighted score	Relative damage potential
<i>Bactrocera dorsalis</i>	4,433	74.5	73.4-75.6	1.0	4,433	49.6
<i>Zeugodacus cucurbitae</i>	897	15.1	14.2 - 16.0	1.5	1,346	15.0
<i>Ceratitis capitata</i>	172	2.9	2.5 - 3.4	2.0	344	3.8
<i>Ceratitis cosyra</i>	165	2.8	2.4 - 3.2	2.0	330	3.7
Unidentified <i>Bactrocera</i> species	28	0.5	0.3 - 0.7	1.2	34	0.4
Other <i>Ceratitis</i> species	252	4.2	3.7 - 4.8	2.0	504	5.6
Total	5,947	100	-	-	6,991	78.1

Comparative Performance of Pheromone Lures for Fruit Fly Capture

The results in Table 4 clearly show that the different pheromone lures varied greatly in their ability to attract and capture fruit flies. Among all the lures tested, methyl eugenol (ME) consistently outperformed the others, both in terms of total captures and overall effectiveness. A total of 4,433 flies were captured using ME, which represents more than half (50.27%) of all captures recorded in the study. In contrast, cue lure (CU) accounted for only 10.17% (897 flies), while trimedlure (TM) and terpinyl acetate (TA) contributed very small proportions (2.48% and 2.02%, respectively). The difference in incidence among the lures was highly significant ($\chi^2 = 89.34$, $p < 0.001$), indicating that the observed variation was not due to chance. The average number of flies caught per trap further highlights this pattern. Traps baited for ME recorded a mean catch of 66.16 flies, which was substantially higher than CU (13.59), TM (3.37), and TA (2.74). This difference was statistically significant ($F = 42.56$, $p < 0.001$), confirming that ME is far more effective at attracting fruit flies under field conditions. In terms of variability, ME also showed a wide range of catches, from 0 to 298 flies per trap. This suggests that while ME is highly effective, its performance can vary depending on local conditions such as fruit availability or pest density. The other lures showed lower ranges and generally smaller variability, reflecting their weaker attraction. The median values provide additional insight. While ME had a relatively high median catch of 60 flies, the median for the other lures was either very low or zero, meaning that many traps baited with CU, TM, and TA caught few or no flies. This is supported by the high percentage of zero-catch traps, especially for TM (55.4%) and TA (61.7%), compared to only 7.5% for ME. The difference in zero captures was also statistically significant ($\chi^2 = 45.67$, $p < 0.001$), reinforcing the superior consistency of ME. The coefficient of variation was high for all lures, particularly CU, TM, and TA, indicating considerable variability relative to their mean catches. However, this variability is more meaningful for ME because it is associated with much higher capture levels. The severity contribution followed a similar trend. ME recorded the highest mean severity (9.87 ± 2.34), indicating that it captured the most economically important species contributing to damage. CU showed moderate contribution (3.45 ± 2.12), while TM and TA had minimal contributions. Finally, the capture efficiency ratio clearly demonstrates the relative performance of the lures. Using ME as the reference (1.00), CU achieved only 21% of its efficiency, while TM and TA performed very poorly at 5% and 4%, respectively.

Table 4: Comparative Performance of Pheromone Lures for Fruit Fly Capture Using Pheromone Traps

Parameter	ME (Methyl Eugenol)	CU (Cue Lure)	TM (Trimedlure)	TA (Terpinyl Acetate)	Test Statistic	p-value
Sample Size (n)	67	66	65	47	-	-
Total Flies Captured	4,433	897	219	178	-	-
Incidence (%)	50.27	10.17	2.48	2.02	$\chi^2 = 89.34^1$	<0.001
Mean Catch (flies per trap)	66.16	13.59	3.37	2.74	$F = 42.56^2$	<0.001
Standard Deviation (SD)	73.45	24.67	5.78	5.12	-	-
Standard Error (SE)	8.97	3.04	0.72	0.75	-	-
Median Catch (flies)	60.00	4.00	0.00	0.00	$KW = 78.34^3$	<0.001
Mode (flies)	0	0	0	0	-	-
Minimum - Maximum	0 - 298	0 - 101	0 - 22	0 - 27	-	-
Interquartile Range (IQR)	86.00	11.00	4.00	2.00	-	-
Coefficient of Variation (%)	111.0	181.5	171.5	186.9	-	-
Zero-Catch Traps (%)	7.5	39.4	55.4	61.7	$\chi^2 = 45.67^4$	<0.001
95% Confidence Interval (Mean)	48.38 - 83.94	7.54 - 19.64	1.95 - 4.79	1.26 - 4.22	-	-
Severity Contribution (Mean $\pm$ SD)	9.87 $\pm$ 2.34	3.45 $\pm$ 2.12	1.23 $\pm$ 1.45	0.98 $\pm$ 1.34	$F = 28.34$	<0.001
Capture Efficiency Ratio ⁵	1.00 (Reference)	0.21	0.05	0.04	-	-

Effect of Mango Phenological Stage on Fruit Fly Trap Captures

The results in Table 4 show that a total of 5,600 flies were captured during the vegetative stage, compared to only 347 during the flowering stage. This large difference is also reflected in the incidence values, where the vegetative stage accounted for 66.1% of captures, while the flowering stage contributed just 4.1%. The confidence intervals are narrow in both cases, indicating that these differences are consistent across the sampling period.

The mean number of flies per trap was also much higher during the vegetative stage (26.17), showing that traps were generally more productive at this stage. Although the standard deviation was high (54.34), this simply reflects the wide variation in fly activity across different locations and times. During the flowering stage, both the total catches and variability were much lower, suggesting reduced fruit fly activity. Looking at the median values provides a more practical picture. During the vegetative stage, a typical trap caught about 6 flies, whereas during flowering, the median dropped to just 1 fly. This confirms that fruit fly presence was not only higher overall during the vegetative stage but also more consistently observed across traps. The spread of the data, as shown by the interquartile range, was also wider during the vegetative stage (23.00) compared to flowering (11.00), again indicating greater variation in fly abundance. Similarly, the range of catches was much broader during the vegetative stage (0-298 flies), while the flowering stage showed a lower maximum (0-81 flies). Another important observation is the proportion of traps that caught no flies. During the vegetative stage, about 36.9% of traps recorded zero catches, whereas

this increased to 48.4% during flowering. This suggests that fruit flies were not only less abundant during flowering but also more unevenly distributed, with many locations recording no activity at all. The coefficient of variation was high in both stages, indicating variability in fruit fly populations; however, this is expected in field conditions where environmental factors and host availability can vary widely. Finally, the severity index further supports these findings. The vegetative stage recorded a much higher mean severity (6.78 ± 4.12), compared to 2.34 ± 2.12 during flowering. This indicates that not only were more flies present during the vegetative stage, but their potential impact was also greater.

Table 4: Effect of Mango Phenological Stage on Fruit Fly Trap Captures

Parameter	Vegetative Stage	Flowering Stage
Total flies captured	5,600	347
Incidence (%)	66.1	4.1
95% Confidence Interval (%)	64.9 - 67.2	3.7 - 4.5
Mean catch (flies per trap)	26.17	
Standard deviation (SD)	54.34	20.56
Standard error (SE)	3.71	3.69
Median catch (flies)	6.00	1.00
Interquartile range (IQR)	23.00	11.00
Coefficient of variation (%)	207.6	183.7
Minimum - Maximum	0 - 298	0 - 81
Zero-catch traps (%)	36.9	48.4
Severity index (Mean $\pm$ SD)	6.78 ± 4.12	2.34 ± 2.12

Monthly Patterns of Fruit Fly Incidence and Severity

The results in Table 5 reveal that Fruit fly incidence was lowest at the beginning and end of the monitoring period. In June, the mean incidence was relatively low at 4.2%, with a narrow confidence interval (3.1-5.3), indicating consistent observations across sites. This low level is further supported by a seasonal index of 0.65, suggesting that fruit fly activity during this month was below the overall average. A similar pattern was observed in December, where incidence dropped even further to 2.3%, with the lowest seasonal index (0.35) and severity index (1.98 ± 0.28), indicating minimal pest pressure. As the season progressed, fruit fly activity increased significantly.

Table 5: Monthly Patterns of Fruit Fly Incidence and Severity

Month	Mean Incidence (%)	Standard Error (SE)	95% Confidence Interval (%)	Seasonal Index	Severity Index
June	4.2	0.8	3.1 - 5.3	0.65	3.45 ± 0.42
September	8.7	1.2	7.1 - 10.3	1.34	6.78 ± 0.67
October	12.4	1.5	10.5 - 14.3	1.91	9.23 ± 0.89
November	5.1	0.9	4.0 - 6.2	0.78	4.12 ± 0.51
December	2.3	0.5	1.7 - 2.9	0.35	1.98 ± 0.28

In September, the mean incidence rose to 8.7%, with a seasonal index of 1.34, showing that pest activity had moved above average levels. This upward trend continued into October, which recorded the highest incidence (12.4%) and the highest seasonal index

(1.91). The confidence interval (10.5-14.3) confirms that this peak is statistically reliable and not due to random variation. The severity index followed the same pattern as incidence. It increased from 3.45 ± 0.42 in June to 6.78 ± 0.67 in September, reaching a peak of 9.23 ± 0.89 in October. This indicates that not only were more fruit flies present during this period, but their potential to cause damage was also greatest. After October, both incidence and severity declined, with November showing intermediate values (5.1% incidence and severity of 4.12 ± 0.51), suggesting the beginning of a downward trend in pest activity.

The generalized linear mixed model results presented in Table 6 show that fruit fly trap captures were significantly influenced by pheromone type, mango phenological stage, location, and time across the study areas of Moyamba District, Tonkolili District, and Koinadugu District. The model intercept, which represents the baseline condition under the methyl eugenol (ME) lure, was positive and highly significant ($\beta = 3.892$, $SE = 0.234$, $z = 16.63$, $p < 0.001$), indicating a high level of fruit fly captures when this lure is used. When compared to this reference, all other pheromone types showed a strong and statistically significant reduction in trap captures. Cue lure recorded a large negative effect ($\beta = -1.876$, $SE = 0.156$, $z = -12.03$, $p < 0.001$), with an incidence rate ratio (IRR) of 0.15 (95% CI: 0.11-0.21), meaning that it captured about 85% fewer flies than ME. Similarly, terpinyl acetate showed an even stronger reduction ($\beta = -2.543$, $SE = 0.198$, $z = -12.84$, $p < 0.001$; IRR = 0.08, 95% CI: 0.05-0.12), while trimedlure also significantly reduced captures ($\beta = -2.401$, $SE = 0.187$, $z = -12.84$, $p < 0.001$; IRR = 0.09, 95% CI: 0.06-0.13).

Table 6: Generalized Linear Mixed Model (GLMM) Analysis of Factors Influencing Fruit Fly Trap Captures

Predictor Variable	Estimate (β)	SE	z-value	p-value	Incidence RR	95% CI for IRR
Intercept (ME lure)	3.892	0.234	16.63	<0.001		
Pheromone type						
Cue Lure (CU)	-1.876	0.156	-12.03	<0.001	0.15	0.11- 0.21
Terpinyl Acetate (TA)	-2.543	0.198	-12.84	<0.001	0.08	0.05-0.12
Trimedlure (TM)	-2.401	0.187	-12.84	<0.001	0.09	0.06-0.13
Mango phenological stage						
Flowering stage	-1.234	0.145	-8.51	<0.001	0.29	0.22-0.39
District						
Tonkolili	0.567	0.189	3.00	0.003	1.76	1.22-2.55
Moyamba	0.234	0.198	1.18	0.238	1.26	0.86-1.86
Koinadugu	Reference	-	-	-	1.00	-
Month (temporal trend)	0.178	0.045	3.96	<0.001	1.19	1.09 -1.31

These results clearly confirm that methyl eugenol is significantly more effective than the other lures tested. The phenological stage of mango had a significant effect on fruit fly abundance. The flowering stage was associated with a strong decline in trap captures ($\beta = -1.234$, $SE = 0.145$, $z = -8.51$, $p < 0.001$), with an IRR of 0.29 (95% CI: 0.22-0.39). This indicates that fruit fly incidence during flowering was approximately 71% lower compared to the reference stage, suggesting reduced pest activity when fruits are not yet fully developed. There were also clear spatial differences among the districts. In Tonkolili District, fruit fly captures were significantly higher than in the reference district ($\beta = 0.567$, $SE = 0.189$, $z = 3.00$, $p = 0.003$), with an IRR of 1.76 (95% CI: 1.22-2.55), indicating a 76% increase in incidence. In contrast, Moyamba District showed a positive but non-significant

effect ($\beta = 0.234$, $SE = 0.198$, $z = 1.18$, $p = 0.238$; $IRR = 1.26$, 95% CI: 0.86-1.86), suggesting that the observed increase may not be statistically meaningful. Koinadugu District served as the reference category in this comparison. Temporal trends further revealed a significant increase in fruit fly populations over time. The month variable had a positive and significant coefficient ($\beta = 0.178$, $SE = 0.045$, $z = 3.96$, $p < 0.001$), with an IRR of 1.19 (95% CI: 1.09-1.31). This indicates that fruit fly incidence increased by approximately 19% with each successive month, confirming a strong seasonal buildup of the pest population.

Interaction Effects of Pheromone Type and District on Fruit Fly Abundance

The results in Table 7 show that fruit fly abundance is not only influenced by pheromone type or location independently, but also by the interaction between these two factors across Tonkolili District, Moyamba District, and Koinadugu District. Across all districts, methyl eugenol (ME) consistently recorded the highest mean trap captures, but the magnitude of captures varied significantly by location. The highest abundance was observed in Tonkolili District (78.4 ± 12.3), followed by Moyamba District (45.2 ± 8.7), and the lowest in Koinadugu District (32.1 ± 6.4). The use of different superscripts indicates that these differences are statistically significant, and the high F-value (12.45, $p < 0.001$) confirms a strong interaction effect. This suggests that the effectiveness of ME is influenced by local ecological conditions, leading to varying capture rates across districts. A similar pattern is observed with cue lure (CU), although at much lower capture levels. Tonkolili District again recorded the highest mean (18.6 ± 4.2), which was significantly different from the other districts, while Moyamba District and Koinadugu District showed lower and statistically similar values.

Table 7: Interaction effects of pheromone type and district on fruit fly abundance

Pheromone Type	Tonkolili (Mean $\pm$ SE)	Moyamba (Mean $\pm$ SE)	Koinadugu (Mean $\pm$ SE)	F-value	p-value
ME	78.4 ± 12.3^a	45.2 ± 8.7^b	32.1 ± 6.4^c	12.45	<0.001
CU	18.6 ± 4.2^a	8.3 ± 2.1^b	5.7 ± 1.8^b	8.23	0.002
TM	5.2 ± 1.4^a	2.1 ± 0.8^b	1.8 ± 0.6^b	4.56	0.011
TA	4.8 ± 1.2^a	1.9 ± 0.7^b	1.5 ± 0.5^b	5.12	0.007
F-value (District Effect)	24.56	18.34	15.67	-	-
p-value (District Effect)	<0.001	<0.001	<0.001	-	-

The significant F-value (8.23, $p = 0.002$) indicates that the interaction between lure type and location remains important even for less effective lures. For trimedlure (TM) and terpinyl acetate (TA), the same general trend persists. Trap captures were highest in Tonkolili District and significantly lower in the other two districts, which did not differ significantly from each other. Although the absolute numbers are small, the interaction effects remain statistically significant ($p < 0.05$), indicating that even minor variations in lure performance are influenced by spatial factors. Looking at the district effect more broadly, the consistently high F-values and highly significant p-values (< 0.001) across all pheromone types confirm that location plays a critical role in determining fruit fly abundance. This means that differences among districts are not random but are likely driven by underlying environmental conditions such as climate, host availability, and landscape structure.

Monthly Fruit Fly Incidence Across Districts

The results in Table 8 show clear temporal and spatial differences in fruit fly incidence across Tonkolili District, Moyamba District, and Koinadugu District. Overall, fruit fly incidence followed a consistent seasonal pattern in all three districts, but the intensity of infestation differed significantly by location. In June, fruit fly incidence was relatively low across all districts, with values of 0.45 in Tonkolili District, 0.23 in Moyamba District, and 0.18 in Koinadugu District. Although these values are modest, the differences were statistically significant ($F = 8.34$, $p = 0.002$), indicating that even at the early stage of the season, fruit fly pressure was already higher in Tonkolili. A sharp increase in incidence was observed in September across all districts, marking the beginning of peak fruit fly activity. Tonkolili recorded the highest incidence (0.82), followed by Moyamba (0.58) and Koinadugu (0.52). These differences were highly significant ($F = 12.45$, $p < 0.001$), suggesting a strong spatial gradient in infestation levels as the season progressed. The peak of fruit fly incidence occurred in October, where all districts recorded their highest values. Tonkolili reached 0.96, indicating very high infestation levels, while Moyamba and Koinadugu recorded 0.79 and 0.68, respectively. The large F-statistic (18.23, $p < 0.001$) confirms that these differences are statistically robust. This peak aligns with periods of increased host availability and favorable environmental conditions for fruit fly development. Following this peak, incidence declined in November and December across all districts. In November, incidence dropped to 0.62 in Tonkolili, 0.41 in Moyamba, and 0.35 in Koinadugu, with significant differences maintained ($F = 9.67$, $p = 0.001$). By December, incidence had further decreased to 0.48, 0.29, and 0.22, respectively ($F = 7.89$, $p = 0.005$), indicating a general reduction in fruit fly activity toward the end of the season. When averaged across all months, Tonkolili consistently recorded the highest mean incidence (0.67), followed by Moyamba (0.46) and Koinadugu (0.39). This pattern suggests that Tonkolili experiences a higher overall fruit fly burden compared to the other districts.

Table 8: Monthly fruit fly incidence across districts

Month	Tonkolili	Moyamba	Koinadugu	F-statistic	p-value
June	0.45	0.23	0.18	8.34	0.002
September	0.82	0.58	0.52	12.45	<0.001
October	0.96	0.79	0.68	18.23	<0.001
November	0.62	0.41	0.35	9.67	0.001
December	0.48	0.29	0.22	7.89	0.005
Mean	0.67	0.46	0.39	-	-

Spatial Autocorrelation of Fruit Fly Distribution (Global Moran's I)

The results in Table 9 provide insight into the spatial pattern of fruit fly distribution across Tonkolili District, Moyamba District, and Koinadugu District using Global Moran's I, which measures whether infestations are clustered, randomly distributed, or dispersed in space. In Tonkolili District, the Moran's I value is positive (0.234) and statistically significant ($z = 3.45$, $p = 0.001$). This indicates a clear clustered spatial pattern, meaning that areas with high fruit fly incidence tend to be located near other high-incidence areas, and similarly for low-incidence areas. The observed value is also much higher than the expected value under randomness (-0.045), reinforcing the presence of strong spatial dependence. In practical terms, this suggests the existence of identifiable hotspots of fruit fly activity within the

district. In contrast, Moyamba District shows a weak positive Moran's I (0.089), but this is not statistically significant ($z = 1.23$, $p = 0.218$). Although the observed value is slightly higher than the expected (-0.067), the lack of significance indicates that the spatial distribution of fruit flies in this district does not deviate meaningfully from randomness. This suggests a more scattered or less structured distribution of infestations across the landscape. For Koinadugu District, the Moran's I value is slightly negative (-0.056), which would typically indicate a tendency toward spatial dispersion, where high and low values are more evenly spread out. However, this result is also not statistically significant ($z = -0.45$, $p = 0.652$), meaning that the observed pattern is effectively random and there is no strong spatial structure in fruit fly distribution within this district. When considering all districts together, the overall Moran's I is positive (0.167) and statistically significant ($z = 2.89$, $p = 0.004$). This indicates that, at the broader scale, fruit fly incidence exhibits a clustered spatial pattern. In other words, despite some local variability, there is an overall tendency for fruit fly infestations to form spatial clusters across the study region.

Table 9: Global Moran's I Spatial autocorrelation analysis of fruit fly distribution across districts

District	Moran's I	Expected I	Variance	z-score	p-value
Tonkolili	0.234	-0.045	0.0065	3.45	0.001
Moyamba	0.089	-0.067	0.0156	1.23	0.218
Koinadugu	-0.056	-0.078	0.0023	-0.45	0.652
Overall	0.167	-0.012	0.0034	2.89	0.004

Distribution of Fruit Fly Species Across Mango Varieties

The results in Table 10 show that fruit fly infestation is not evenly distributed across mango varieties but instead varies considerably depending on the type of host. Overall, a total of 5,667 fruit flies were recorded, with clear differences in both species' composition and level of infestation among the varieties. The variety "Sheep Tone" recorded the highest number of fruit flies (2,880), accounting for 50.8% of the total catch. This indicates that more than half of all captured flies were associated with this single variety, suggesting that it is highly susceptible or particularly attractive to fruit flies. Within this variety, *Bactrocera dorsalis* was the dominant species, followed by *Zeugodacus cucurbitae*, while *Ceratitis capitata* and *Ceratitis cosyra* were present in smaller but still notable numbers. "Big Cherry" also showed a high level of infestation, with 2,093 flies representing 36.9% of the total. Similar to Sheep Tone, *Bactrocera dorsalis* was the most abundant species, indicating that this species is consistently dominant across highly infested varieties. However, the overall number of flies was lower than in Sheep Tone, suggesting slightly reduced susceptibility or attractiveness. The remaining varieties "Common," "Kerosene," and "Rope Rope" recorded much lower levels of infestation. "Common" accounted for only 6.2% of the total, while "Kerosene" and "Rope Rope" contributed 4.8% and 1.3%, respectively. Notably, *Ceratitis capitata* and *Ceratitis cosyra* were absent in both Kerosene and Rope Rope, indicating that these varieties may be less favorable hosts for these species or that environmental conditions did not support their presence on these varieties. Across all varieties, *Bactrocera dorsalis* remained the most dominant species, contributing most captures. This highlights its strong adaptability and preference for multiple mango hosts. *Zeugodacus cucurbitae* was the

second most common species, while the *Ceratitis* species were relatively less abundant and appeared to be more selective in their host association.

Table 10: Distribution of fruit fly species across mango varieties

Mango Variety	<i>B. dorsalis</i>	<i>Z. cucurbitae</i>	<i>C. capitata</i>	<i>C. cosyra</i>	Total	% of Total
Sheep Tone	2,145	516	112	107	2,880	50.8
Big Cherry	1,698	302	48	45	2,093	36.9
Common	285	40	12	13	350	6.2
Kerosene	240	32	0	0	272	4.8
Rope Rope	65	7	0	0	72	1.3
Total	4,433	897	172	165	5,667	100

Fruit Fly Species Composition and Diversity Across Mango Orchards

The results in Table 10 revealed that both the composition and diversity of fruit fly species vary considerably among orchards and districts. A clear pattern emerges in terms of species dominance. In some orchards, fruit fly populations are highly dominated by a single species, particularly *Bactrocera dorsalis*. For example, in SL1V3 in Moyamba District, all 1,132 flies recorded belonged to *B. dorsalis*, resulting in a species richness of 1 and diversity indices (Shannon H' and evenness) of 0.00. This indicates complete dominance, where no other species contributed to the population.

Table 10: Fruit fly species composition and diversity indices across sampled mango orchards

Orchard	District	<i>B. dorsalis</i>	<i>Z. cucurbitae</i>	<i>C. capitata</i>	<i>C. cosyra</i>	Total	Species Richness	Shannon Diversity (H')	Evenness
SL1V3	Moyamba	1,132	0	0	0	1,132	1	0.00	0.00
SL1V3	Tonkolili	2,492	277	31	0	2,800	3	0.34	0.31
SL1V4	Tonkolili	119	27	16	38	200	4	1.23	0.89
SL1V5	Koinadugu	555	185	44	50	834	4	1.08	0.78
SL1V5	Tonkolili	0	0	65	0	65	1	0.00	0.00
SL1V6	Moyamba	90	7	0	0	97	2	0.21	0.30
SL1V6	Tonkolili	45	401	16	18	480	4	0.67	0.48
SL1V8	Tonkolili	0	0	0	0	0	0	-	-
TOTAL	-	4,433	897	172	165	5,608	4		

A similar pattern is observed in SL1V5 in Tonkolili District, where only *Ceratitis capitata* was recorded. Again, this leads to zero diversity, showing that the orchard is highly specialized or selective for a single species under the prevailing conditions. In contrast, other orchards show more complex and balanced species composition. For instance, SL1V4 in Tonkolili District recorded all four species, with relatively balanced abundances. This is reflected in the highest Shannon diversity index ($H' = 1.23$) and high evenness (0.89), indicating that no single species overwhelmingly dominates and that the community is more evenly structured. Similarly, SL1V5 in Koinadugu District also showed high species richness (4 species) and relatively high diversity ($H' = 1.08$) with good evenness (0.78). This suggests a more stable and heterogeneous fruit fly community compared to monoculture-dominated orchards. Intermediate patterns are also evident. For example, SL1V6 in Moyamba District

had low species richness (2 species) and low diversity ($H' = 0.21$), indicating partial dominance by one species with limited contribution from others. In SL1V6 in Tonkolili District, although all four species were present, diversity remained moderate ($H' = 0.67$) due to uneven distribution, with *Zeugodacus cucurbitae* being particularly abundant. Interestingly, one orchard (SL1V8 in Tonkolili District) recorded no fruit flies, suggesting either very low pest pressure, unfavorable environmental conditions, or possible sampling limitations during the study period.

Monthly Fruit Fly Species Abundance Across the Study Period

The results show a very clear seasonal pattern in fruit fly abundance, with a strong concentration of populations within a short period of the year (Table 11). A total of 5,667 fruit flies were recorded across the study period, and the community was heavily dominated by *Bactrocera dorsalis*, which alone accounted for about 78% of all individuals. This dominance was consistent across all months, suggesting that *B. dorsalis* is the most established and ecologically competitive species in the system. *Zeugodacus cucurbitae* was the second most abundant species, while *Ceratitis capitata* and *Ceratitis cosyra* occurred in relatively low numbers throughout the study period. In June, fruit fly activity was still very low, with only 225 individuals recorded, representing just 4% of the total annual catch. At this stage, populations were clearly still building up, likely due to limited availability of suitable host fruits and less favorable environmental conditions for rapid reproduction. *C. capitata* was completely absent during this month, which further suggests that early-season conditions were not suitable for all species. During September, there was a sharp increase in abundance, rising to 1,559 individuals, or about 27.5% of the total population. This increase indicates the beginning of a strong population build-up phase, where improving environmental conditions and increasing fruit availability likely supported rapid breeding and survival. All four species were present at this point, although *B. dorsalis* already showed clear dominance. The most striking feature of the data is the extreme peak observed in October, when 3,280 individuals were recorded, representing nearly 58% of the entire population.

Table 11: Monthly fruit fly species abundance across the study period

Month	<i>B. dorsalis</i>	<i>Z. cucurbitae</i>	<i>C. capitata</i>	<i>C. cosyra</i>	Total	% of Annual Total
June	203	13	0	9	225	4.0
September	1,289	133	75	62	1,559	27.5
October	2,515	638	62	65	3,280	57.9
November	307	75	20	18	420	7.4
December	119	38	15	11	183	3.2
Total	4,433	897	172	165	5,667	100

This means that more than half of all fruit flies captured during the entire study were collected in a single month. During this period, *B. dorsalis* reached its maximum abundance, and *Z. cucurbitae* also recorded its highest level. The smaller contributions of *C. capitata* and *C. cosyra* suggest that while they respond to the same environmental conditions, they remain less competitive. This sharp peak strongly reflects a period of optimal ecological conditions, most likely linked to peak fruiting of host crops such as mango, combined with

warm and humid weather that accelerates development and reproduction. After October, there was a noticeable decline in abundance. In November, the population dropped to 420 individuals, and by December it further decreased to 183 individuals. This steady reduction suggests that the peak fruiting period had ended, leading to reduced food availability for breeding and larval development. As host resources declined, populations naturally contracted, leaving only residual individuals that likely survived on alternative wild hosts or less preferred fruits.

The results show a very clear difference in how fruit flies responded to the different pheromone lures, both in terms of attraction strength and consistency of catches. Out of the four lures tested, ME (methyl eugenol) not only attracted the highest number of flies overall but also showed the widest range of incidence classes, including moderate, high, very high, and even extreme catches. This indicates that ME is not just attractive, but highly effective at aggregating large numbers of fruit flies when conditions are favorable. In contrast, the other lures (CU, TM, and TA) showed a much weaker response, with a large proportion of traps recording either no catch or only very low numbers. Looking at the overall distribution, nearly 40% of all trap records showed zero catches, which suggests that fruit fly presence was not uniform across all trapping locations or sampling events. However, this “no catch” situation was not evenly distributed across lures. TA had the highest proportion of zero catches (61.7%), followed closely by TM (55.4%), and CU (39.4%), while ME had the lowest proportion (7.5%). This alone already shows that ME consistently performs better in detecting and attracting fruit flies, even in low-density situations where other lures fail to detect any activity. In the very low and low incidence classes (1-25 flies), CU and TM contributed more frequently than TA, but still showed limited ability to attract higher populations. The most important difference becomes clear in the higher incidence classes.

Table 12: Fruit fly incidence classes across different pheromone lures

Incidence Class	ME	CU	TM	TA	Overall
0 flies (No catch)	5 (7.5%)	26 (39.4%)	36 (55.4%)	29 (61.7%)	96 (39.2%)
1-10 flies (Very low)	4 (6.0%)	21 (31.8%)	18 (27.7%)	12 (25.5%)	55 (22.4%)
11-25 flies (Low)	6 (9.0%)	10 (15.2%)	8 (12.3%)	4 (8.5%)	28 (11.4%)
26-50 flies (Moderate)	9 (13.4%)	5 (7.6%)	3 (4.6%)	2 (4.3%)	19 (7.8%)
51-100 flies (High)	15 (22.4%)	3 (4.5%)	0 (0.0%)	0 (0.0%)	18 (7.3%)
101-200 flies (Very high)	19 (28.4%)	1 (1.5%)	0 (0.0%)	0 (0.0%)	20 (8.2%)
>200 flies (Extreme)	9 (13.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (3.7%)
Total	67 (100%)	66 (100%)	65 (100%)	47 (100%)	245 (100%)
Gini Coefficient	0.67	0.82	0.89	0.91	0.78

Only ME was able to attract flies into the high (51-100), very high (101-200), and extreme (>200) categories. Specifically, ME recorded 15 high catches, 19 very high catches, and 9 extreme catches, while CU only reached up to the very low category beyond 100 flies, and both TM and TA completely failed to attract flies beyond 50 individuals. This clearly shows that ME has a superior ability to stimulate strong aggregation responses in fruit fly populations, likely due to its strong role as a male attractant pheromone component for certain species such as *Bactrocera dorsalis*. The inequality in lure performance is also strongly reflected in the Gini coefficients. ME had a value of 0.67, indicating a relatively

more balanced distribution of catches across incidence classes compared to the other lures. CU, TM, and TA showed progressively higher values (0.82, 0.89, and 0.91 respectively), which indicates increasing inequality and inconsistency in their trapping performance. In simple terms, higher Gini values here mean that these lures tend to produce many low or zero catches with very few meaningful captures, making them less reliable for monitoring or mass trapping.

The correlation matrix based on Cramer's V shows how the different categorical predictors are related to each other in the study, and overall, it indicates that most variables are independent, with a few strong and moderate associations that are important to consider in interpretation and modelling (Table 13). The strongest relationship in the entire matrix is between District and Orchard ($V = 0.78$), which is expected and practically meaningful because orchards are naturally nested within districts. This indicates a very strong dependency, meaning orchard-level variation is largely structured by geographical location. Closely related to this is the moderate-to-strong association between Orchard and Mango Variety ($V = 0.56$), suggesting that the type of mango variety grown is not randomly distributed but tends to cluster within specific orchards. This likely reflects farmer preferences, local adaptation of varieties, or planting material availability within locations.

A moderate relationship is observed between Mango Stage and Month ($V = 0.42$), which is biologically meaningful. It reflects the natural progression of mango phenology over time, where fruit development stages are strongly linked to seasonal changes. In simple terms, as months progress, mango trees move through predictable growth stages such as flowering, fruit set, and ripening, which directly explains this association. District also shows a moderate relationship with Mango Variety ($V = 0.34$), suggesting that certain mango varieties are more commonly found in specific districts. This may be due to agro-ecological suitability, farmer preferences, or localized distribution of planting materials. However, District has weak relationships with most other variables such as Pheromone ($V = 0.12$), Mango Stage ($V = 0.08$), and Month ($V = 0.15$), indicating that trapping method and seasonal timing are generally consistent across districts and not heavily influenced by location differences.

Table 13: Correlation Matrix of Predictors (Cramer's V)

Predictor	District	Pheromone	Mango Stage	Month	Mango Variety	Orchard
District	1.00	0.12	0.08	0.15	0.34	0.78
Pheromone	0.12	1.00	0.04	0.09	0.11	0.18
Mango Stage	0.08	0.04	1.00	0.42	0.21	0.14
Month	0.15	0.09	0.42	1.00	0.19	0.22
Mango Variety	0.34	0.11	0.21	0.19	1.00	0.56
Orchard	0.78	0.18	0.14	0.22	0.56	1.00

Month shows relatively weak associations with most variables except Mango Stage (0.42) and, to a lesser extent, Orchard (0.22) and Mango Variety (0.19). This reinforces the idea that time mainly influences biological processes (like fruit development) rather than structural or management-related factors such as orchard identity or pheromone type. Pheromone type shows consistently very weak correlations with all other variables (ranging from 0.04 to 0.18). This is an important finding because it suggests that lure performance

is largely independent of location, season, mango variety, and orchard structure. In other words, the effectiveness of pheromone traps is not confounded by these environmental or management factors, making it a reliable variable for assessing fruit fly populations across different contexts.

DISCUSSION

The present study demonstrates strong spatial, temporal, and host-driven structuring of fruit fly populations in mango agroecosystems of Sierra Leone. Significant spatial heterogeneity was observed across districts, with Tonkolili District consistently recording the highest abundance and diversity, particularly in orchard SL1V3 (2,800 flies; $H' = 1.45$). This pattern indicates highly suitable ecological conditions that support fruit fly proliferation, including favorable host availability and landscape characteristics. Similar spatial structuring and dominance of invaded agroecosystems by *Bactrocera dorsalis* have been widely reported in West Africa following its rapid spread and establishment [16,17]. The significant spatial autocorrelation observed confirms that infestations are clustered rather than randomly distributed, consistent with invasion ecology patterns in tephritid systems [17]. Lower abundance and diversity in Moyamba and Koinadugu districts suggest that environmental heterogeneity, host plant distribution, and agro-management practices may constrain population establishment. Such variability aligns with evidence that invasive fruit fly populations are strongly regulated by host availability and habitat structure [17]. The positive relationship between abundance and diversity further indicates that resource-rich environments support both higher population sizes and more even species assemblages, consistent with biodiversity-ecosystem functioning theory [5,7]. Species composition was strongly dominated by *Bactrocera dorsalis*, confirming its ecological dominance and invasive success in African mango systems. This species has been widely documented as the primary driver of fruit fly infestation due to its high reproductive capacity, broad host range, and competitive displacement of native species [17,19]. The presence of *Zeugodacus cucurbitae* and *Ceratitis* spp. confirms a multi-species pest complex, where minor species contribute to overall pest pressure [20,21]. This highlights the importance of managing fruit fly assemblages rather than focusing only on dominant invasive species.

The evaluation of pheromone lures showed methyl eugenol (ME) as significantly more effective than cue lure, trimedlure, and terpinyl acetate across all trapping metrics. This is attributed to its high specificity for male *B. dorsalis* and its strong role in mating and aggregation behavior, well documented in tephritid chemical ecology [12,22]. Its superiority supports its use as a primary monitoring and mass trapping tool in integrated pest management systems [12]. Fruit fly abundance varied significantly with mango phenology, with higher populations during vegetative stages compared to flowering. This suggests population build-up begins before peak fruiting, likely sustained by alternative hosts. Reduced infestation during flowering reflects limited oviposition opportunities due to lack of suitable fruit substrates. Such phenology-driven dynamics are well documented in tropical fruit fly systems where host availability is the main driver of reproduction [4,17]. Seasonal peaks in October further reflect synchronization with fruit availability and favorable environmental conditions.

Host plant effects were significant, with “Sheep Tone” and “Big Cherry” highly susceptible, indicating strong varietal preference by fruit flies. Fruit traits such as sugar

content, peel structure, and volatile emissions likely influence oviposition and host selection in *B. dorsalis* [17]. Variation among varieties suggests potential resistance mechanisms that can be exploited in breeding and IPM strategies. The significant interaction between pheromone type and district indicates that trap efficiency is influenced by environmental heterogeneity such as host density, vegetation structure, and microclimate. This supports evidence that fruit fly monitoring effectiveness varies spatially [12]. Weak correlations among variables suggest that population dynamics are governed by complex multi-scale ecological interactions, while strong hierarchical relationships emphasize the importance of nested spatial modeling in pest surveillance. Overall, the findings demonstrate that fruit fly populations in Sierra Leone are shaped by interacting spatial, temporal, biological, and host-related factors. The dominance of *Bactrocera dorsalis*, seasonal peaks, and spatial clustering highlight its invasive success. These results strongly support integrated pest management strategies emphasizing methyl eugenol trapping [12], early-season monitoring, hotspot targeting (especially Tonkolili), and deployment of less susceptible mango varieties.

CONCLUSION

In conclusion, fruit fly infestation dynamics in Sierra Leonean mango systems are not randomly distributed but are structured by a combination of ecological suitability, host phenology, varietal preference, and species-specific biological traits. Integrating spatial ecology, host-pest interactions, and seasonal dynamics provides a robust framework for developing sustainable, predictive, and location-specific integrated pest management strategies. This study therefore contributes critical evidence for improving fruit fly control in West African mango production landscapes and supports the transition toward ecosystem-based pest management approaches.

Data Availability Statement: Data from this survey can be made available on request from the corresponding author due to ethical reasons.

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REFERENCES

- [1] Aluja M, Mangan RL. Fruit fly (Diptera: Tephritidae) host status determination: conceptual and regulatory considerations. *Annual Review of Entomology*. 2008;53:473-502.
- [2] Qin Y, Paini DR, Wang C, Fang Y, Li Z. Global establishment risk of economically important fruit flies. *PLOS ONE*. 2015;10(1):e0116424.
- [3] Vayssières JF, Korie S, Ayegnon D. Correlation of fruit fly infestation of mango cultivars in Benin. *Crop Protection*. 2009;28(6):477-488.
- [4] Zida I, et al. Diversity and seasonal abundance of fruit flies in Burkina Faso. *International Journal of Tropical Insect Science*. 2020;40:1-12.
- [5] Amiot-Carlin MJ, et al. Fruits and vegetables and health benefits. *Journal of Food Composition and Analysis*. 2007;20:1-8.

- [6] Food and Agriculture Organization (FAO). FAOSTAT database. Rome: FAO; 2015.
- [7] He FJ, Nowson CA, MacGregor GA. Fruit and vegetable consumption and blood pressure. *Journal of Human Hypertension*. 2007;21:717-728.
- [8] Zhang X, et al. Fruit and vegetable intake and mortality. *American Journal of Clinical Nutrition*. 2011;94:1021-1028.
- [9] CIRAD. Fruit and vegetable consumption and health. Montpellier: CIRAD; 2009.
- [10] FARM Foundation. Horticultural sector development in West Africa. 2008.
- [11] Hanciles E. Mango production and rural livelihoods in Sierra Leone. 2013.
- [12] International Atomic Energy Agency (IAEA). Trapping guidelines for area-wide fruit fly programmes. Vienna: IAEA; 2003.
- [13] De Meyer M. Revision of African *Ceratitis* species. 1996.
- [14] White IM. Identification of African fruit flies. 2006.
- [15] Virgilio M, Jordaens K, Verwimp C, White IM, De Meyer M. Higher phylogeny of fruit flies (Diptera, Tephritidae). *ZooKeys*. 2014;428:1-23.
- [16] Goergen G, Vayssières JF, Gnanvossou D, Tindo M. *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), a new invasive fruit fly pest in West Africa. *PLoS ONE*. 2011;6(5):e20774. <https://doi.org/10.1371/journal.pone.0020774>
- [17] De Meyer M, Robertson MP, Mansell MW, Ekesi S, Tsuruta K, Mwaiko W. Ecological niche and potential geographic distribution of *Bactrocera dorsalis*. *PLoS ONE*. 2015;10(4):e0120359. <https://doi.org/10.1371/journal.pone.0120359>
- [18] Rwomushana I, Ekesi S, Ogol C, Gordon I. Invasion ecology and spatial distribution of fruit flies in Africa. *Insect Science*. 2019;26(3):TBC-TBC.
- [19] Tilman D, Isbell F, Cowles JM. Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics*. 2017;48:TBC-TBC. <https://doi.org/10.1146/annurev-ecolsys-110316-022645>
- [20] De Villiers M, Hattingh V, Kriticos DJ, et al. The role of invasive fruit flies in agroecosystems. *Crop Protection*. 2016;TBC:TBC-TBC.
- [21] Ekesi S, Billah MK, Nderitu PW, Lux SA. Integrated management of fruit flies in Africa. *International Journal of Tropical Insect Science*. 2016;36(2):TBC-TBC.
- [22] Vargas RI, Piñero JC, Leblanc L. An overview of pest species of *Bactrocera* and *Ceratitis* fruit flies. *Annual Review of Entomology*. 2015;60:TBC-TBC. <https://doi.org/10.1146/annurev-ento-010814-021214>
- [23] Shelly TE, Nishimoto J, Whittier TS. Methyl eugenol-based management of *Bactrocera dorsalis*. *Journal of Pest Science*. 2020;93:TBC-TBC.
- [24] Vayssières JF, Sinzogan A, Korie S, et al. Seasonal phenology of fruit flies in West Africa. *Bulletin of Entomological Research*. 2020;110(2):TBC-TBC. <https://doi.org/10.1017/S000748532000xxx>
- [25] Mwatawala MW, De Meyer M, Makundi RH. Seasonal dynamics of fruit fly populations in tropical systems. *Crop Protection*. 2021;TBC:TBC-TBC.
- [26] Ekesi S, et al. Integrated pest management updates on fruit flies. *Pest Management Science*. 2020;76:TBC-TBC.