

Different effects of local and landscape factors on the population density of two fruit fly species in Indonesian apple orchards

SHERLITA OCTAVINA RACHMA PUTRI[✉], AKHMAD RIZALI^{✉✉}, SILVI IKAWATI

Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya, Jl. Veteran, Malang 65145, East Java, Indonesia.
Tel./fax.: +62-341-565845, ✉email: sherlitaputri@student.ub.ac.id, ✉✉email: arizali@ub.ac.id

Manuscript received: 12 December 2024. Revision accepted: 28 April 2025.

Abstract. Putri SOR, Rizali A, Ikawati S. 2025. Different effects of local and landscape factors on the population density of two fruit fly species in Indonesian apple orchards. *Biodiversitas* 26: 2079-2087. Apple production in Indonesia faces significant challenges due to pests, particularly fruit flies (Diptera: Tephritidae). Recently, management strategies for controlling fruit flies in apple orchards have often overlooked the influence of local and landscape-level factors. The objective of this study is to investigate how these factors affect fruit fly population densities in apple orchard. Research was conducted in nine apple orchards in East Java, Indonesia. For each orchard, the landscape was characterized by manual digitization the area within a 500 m radius from the center of the plot. To sample fruit flies, attractant traps were used along with rearing symptomatic fruits. Three species of fruit flies were identified in the apple orchards, with *Bactrocera carambolae* and *B. dorsalis* being the most abundant. In contrast, *B. umbrosa* was found only in one research site. Using Generalized Linear Model (GLM) analysis, it was determined that local factors, such as the frequency of pesticide application and canopy cover), as well as landscape factors, including class area and the number of patches of semi-natural habitats and apple orchards, influenced the population density of *B. carambolae*. On the other hand, *B. dorsalis* was only affected by a landscape factor, specifically class area of semi-natural habitats. Spatial variation of *B. carambolae* within the apple orchards was also influenced by a local factor (canopy cover) and a landscape factor (class area of semi-natural habitats). However, *B. dorsalis* was not affected by either type of factor. These findings emphasize the importance of understanding local and landscape factors to develop effective management strategies for different species of fruit flies in apple orchards.

Keywords: *Bactrocera carambolae*, *Bactrocera dorsalis*, landscape scale, local scale, management strategies

INTRODUCTION

As a tropical country, Indonesia plays a significant role in apple fruit production, with East Java Province, Indonesia as the main production region, producing 392,173 tons of the total national production of 392,563 tons. In East Java, apple production is concentrated in Malang District (87,023 tons), Batu City (14,028 tons), and Pasuruan District (28,262 tons), making these three regions the main centres of national apple production (Central Statistics Agency of East Java 2024). However, apple production in East Java has been reported to be decreasing, with statistical data showing a decrease from 392,173 tons in 2023 to 129,795 tons in 2024. This is related to land use conversion for other commodities due to pest and disease problems as well as economic considerations by growers due to the high cost of pest and disease control. Excessive use of chemical fertilizers and pesticides increases pest attacks, disrupt the balance of selling prices, and promotes land conversion (Tan and Qi 2023; Gao et al. 2024). Recently, land for apple cultivation has been reported to have shrunk drastically, with data from the Department of Agriculture of the City of Batu showing a decline from 1,098.2 hectares in 2019 to 866.7 hectares in 2021.

Major pests of apple crops include fruit flies, aphids, mites, thrips, and leaf suckers (Li et al. 2024). Fruit flies (Diptera: Tephritidae) are classified as invasive pests that have a major impact on the agricultural sector, particularly

on horticultural crops in tropical and subtropical regions. Their attacks can reduce fruit quality and cause fruit drop and rot, resulting in economic losses due to lower selling prices (Clarke et al. 2005; Louzeiro et al. 2021; Mutamiswa et al. 2021). Research by Grechi et al. (2022) showed that fruit flies can also attack immature fruit, causing damage before the fruit is ready for harvest. The most common genus of fruit flies is *Bactrocera*, with 461 species identified due to its wide distribution and host range (Egartner et al. 2019). Research by Follett et al. (2019) has shown that apple crops are good hosts for fruit flies, especially *B. dorsalis*.

The presence of fruit flies in agricultural areas may be influenced by local and landscape factors. Several studies have shown that local and landscape factors of the surrounding crop fields play an important role in supporting insect populations, including fruit flies in agricultural areas (Ortega and Pascual 2014; Perez-Alvarez et al. 2018; Krasnov et al. 2019; Diallo et al. 2021; Paredes et al. 2023). Local factors that may affect the presence of fruit flies include pesticide application and plant maintenance, such as canopy maintenance and pruning. Research by Inskeep et al. (2021) showed that canopy cover can affect the presence of fruit flies because it can provide refuge for fruit flies from extreme environmental conditions. Research by Petrovskii et al. (2014) and Al-Khoury et al. (2021) showed that intensive pesticide application can cause pests to become resistant and result

in the death of natural enemies and a decrease in their populations, which can lead to a resurgence of pest populations.

Agricultural landscape composition can also affect the biodiversity and population dynamics of fruit flies. An increase in fruit fly population dynamics can result from the loss of semi-natural habitats and the simplification of the landscape (Mitchell et al. 2022). In addition, landscape characteristics can also affect interactions between plants, pests, and natural enemies, such that an increase in the complexity and diversity of landscape composition can reduce populations as well as increase natural enemies and beneficial insects (Perez-Alvarez et al. 2018). Research by Ortega and Pascual (2014) showed that landscape complexity can help reduce fruit fly populations. Research by Araujo et al. (2019) showed that semi-natural habitats and open areas can affect fruit fly populations in apple orchards.

Research specifically investigating the influence of local and landscape factors on insects in apple orchards is limited in Indonesia, primarily because apples are an introduced crop in the country. Furthermore, there is a lack of studies that simultaneously investigate how landscape and local factors affect fruit fly population density. Previous studies have often focused on one fruit fly species without comparing how these potentially overlapping ecological species respond to landscape- and local-scale variation. To increase the effectiveness of natural pest control, a conservation control approach is needed to understand the surrounding orchard management that can reduce fruit fly populations and increase the presence of natural enemies. Therefore, the objective of this study to

fill gap by investigate the effect of local and landscape factors on fruit fly population density comparatively in apple orchards. This will provide valuable insights for more effective pest management.

MATERIALS AND METHODS

Study area

The study was conducted at nine in three locations in Malang, Batu, and Pasuruan, East Java, Indonesia (Figure 1) from October to December 2023, and identification of specimens was done in the Laboratory of Plant Pest, Faculty of Agriculture, Universitas Brawijaya, East Java. The average annual temperature was 18.3-27.2°C, with a precipitation per month of around 132.4 mm (Station of Meteorology Climatology and Geophysics Agency in East Java Province 2023). The nine apple orchards were managed according to intensive farming management practices.

Plot design

The study areas were selected systematically based on criteria by age of apple trees between 10 to 25 years with same varieties, elevation range from 945 to 1335 m asl, and with land area 1,000 m². Each research site had a minimum distance of at least 1 km between research sites to avoid overlapping. At each research site, plots of 21×21 meters (64 trees) were created for trap installation. Within a plot, nine trap installation points were made in a transect manner to obtain a representative sample of the whole field (Crum et al. 2021) (Figure 2).

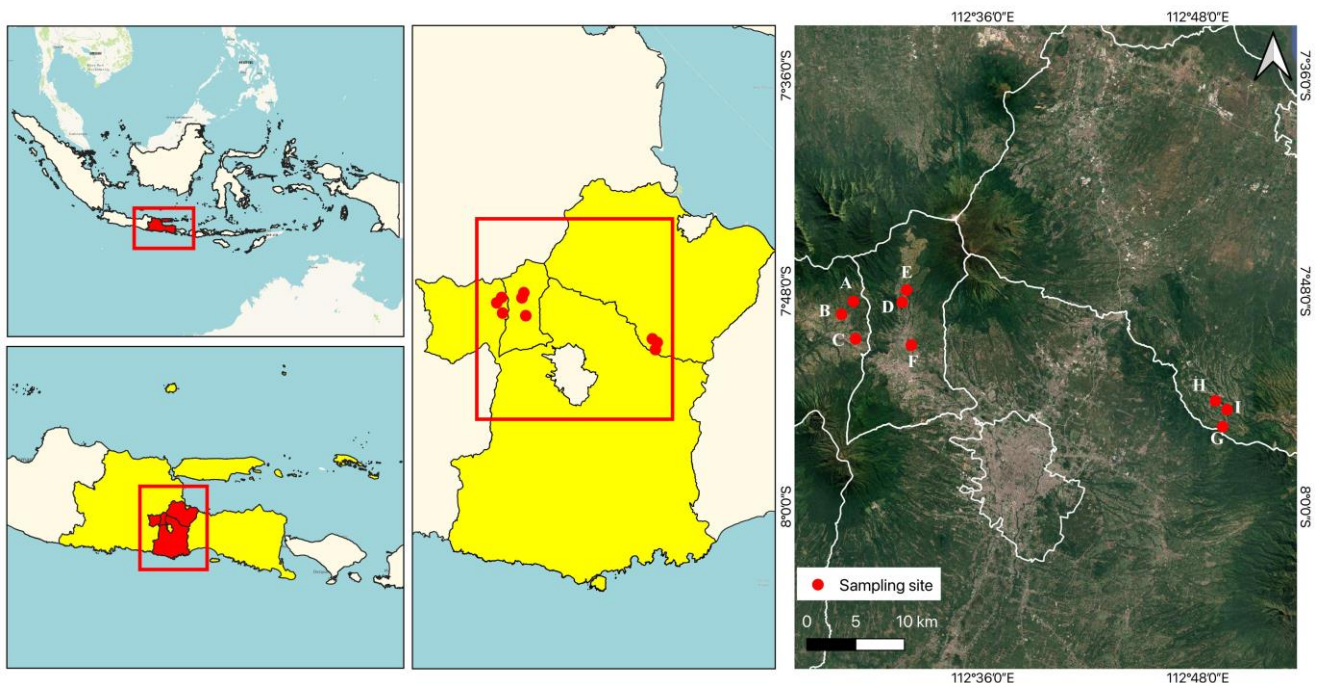


Figure 1. The research sites of nine apple orchards located in Malang District, City of Batu and Pasuruan District, East Java, Indonesia. Site codes: S1: Borah, Malang; S2: Bengkaras, Malang; S3: Jurangrejo, Malang; S4: Gerdu, Batu; S5: Junggo, Batu; S6: Bulukerto, Batu; S7: Blarang, Pasuruan; S8: Taman, Pasuruan; S9: Putur, Pasuruan

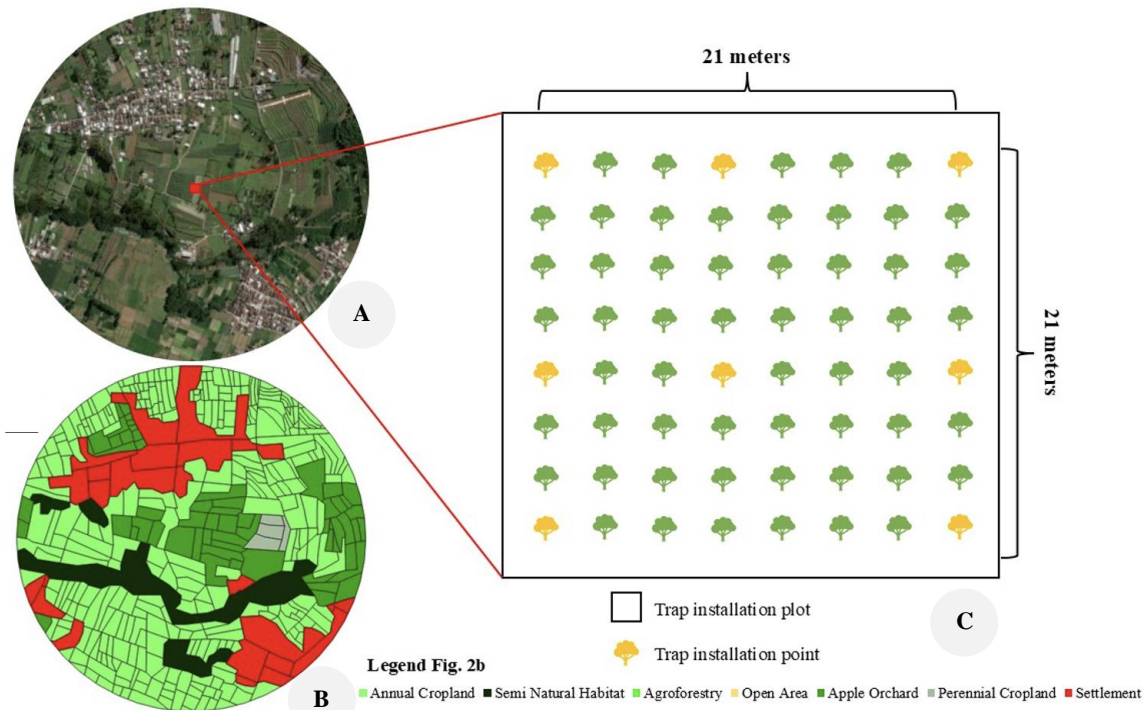


Figure 2. Landscape characterization with a radius 500 meters in one of the research sites. A. Bulukerto; B. Results of landscape digitization in one of the research sites, Bulukerto; C. Observation plots

Habitat condition

Measurement of variables was conducted at the habitat level (local scale) and landscape scale. The local scale factors that were considered to affect the population density of fruit flies are canopy cover and frequency of pesticide application (Table 1). The canopy cover was measured using a photographic method, where photos were taken at five different points in each research site. Photographs were taken in the middle of four apple trees and from the ground towards the canopy with a camera at a height of 30 cm from the ground. The resulting photographs were processed using ImageJ2 to measure the percentage of canopy closeness (Rueden et al. 2017). For another local scale factor of the frequency of monthly pesticide application, data were obtained from farmer interviews.

Characterization of landscape composition

Landscape characterization was conducted by mapping land use types at each research site through ground checking at a radius of 500 m from the plot as the center of the landscape. The ground check was conducted in October 2023 using the map from Google Earth as the base map for the ground check. Digitization was done using QGIS software, which classified land use into seven types: settlement, perennial cropland, apple orchard, open area, agroforestry, semi-natural habitat, and annual cropland (Figure 3). Furthermore, landscape composition was analyzed through Landscape Ecological Statistics (LecoS) with QGIS software, using the composition indices of Number of Patches (NP) and Class Area (CA) (Jung 2013). The analysis was only conducted on the NP and CA of semi-natural habitats and apple orchards.

Sampling of fruit flies

Fruit flies were sampled using an attractant trap method adopted from the research of Pujiastuti et al. (2020). The trap is made from a bottle that putting together with yellow traps and then smeared with 1-2 mL of methyl eugenol and hung on a tree canopy at 1 meter above ground level. Traps were set for 24 hours to facilitate sampling and minimize damage to insect forms. Trapped insects were then brought to the laboratory for identification. Fruit flies were also collected using the host-rearing method adopted from Ramadan et al. (2023) with jars containing sawdust media that had previously been sterilized for an hour at 100°C using an oven. Host rearing was conducted to confirm that the species attacked apple fruit. Symptomatic fruit was placed in a container to minimize contamination between fruit juices and sawdust and was then covered with gauze. When the imago emerged, they were immediately moved into a container containing honey water, which served as an alternative food source. The adults were reared until they were seven days old to obtain the perfect mesonotum color for identification. Insect identification was performed by grouping each specimen to the species level based on the morphology of the found specimens. Morphological identification of fruit flies was carried out based on the identification guidebook ‘The Australian Handbook for the Identification of Fruit Flies 3.1 version 2018’ by Plant Health Australia (2018) and supporting journals. Furthermore, images were taken using an Olympus SZX7 digital microscope.

Table 1. Characteristics of the nine apple orchard sites at the time sampling was conducted according to local factors (frequency of monthly pesticide application and percentage of canopy cover) and landscape factors (class area (CA.nat) and number of patches (NP.nat) of semi-natural habitats and class area (CA.apple) and number of patches (NP.apple) of apple orchards). Site codes: S1: Borah, Malang; S2: Bengkaras, Malang; S3: Jurangrejo, Malang; S4: Gerdu, Batu; S5: Junggo, Batu; S6: Bulukerto, Batu; S7: Blarang, Pasuruan; S8: Taman, Pasuruan; S9: Putur, Pasuruan

Sites code	Local factors		Landscape factors			
	Pesticide application	Canopy cover (%)	CA.nat (ha)	NP.nat	CA.apple (ha)	NP.apple
S1	2	77.56	0	0	18.00	14
S2	4	31.28	9.05	2	26.08	28
S3	8	57.39	7.51	4	12.72	15
S4	4	18.42	2.50	2	41.93	37
S5	2	61.00	0	0	18.63	15
S6	4	41.36	2.54	2	1.97	4
S7	4	46.58	39.88	2	36.96	33
S8	8	40.21	33.22	2	37.24	40
S9	4	37.82	30.63	2	41.38	38

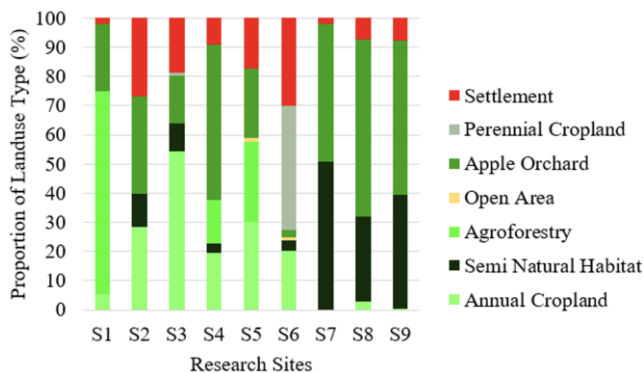


Figure 3. Proportion of land use types in the nine research sites. Site codes: S1: Borah, Malang; S2: Bengkaras, Malang; S3: Jurangrejo, Malang; S4: Gerdu, Batu; S5: Junggo, Batu; S6: Bulukerto, Batu; S7: Blarang, Pasuruan; S8: Taman, Pasuruan; S9: Putur, Pasuruan

Data analysis

The effect of local and landscape factors on the population density of fruit flies was analyzed using a Generalized Linear Model (GLM) without interaction and using quasi-Poisson distribution to explain overdispersion (Bolker et al. 2009). The explanatory variables were Class Area (CA.apple) and Number of Patches (NP.apple) of apple orchards, Class Area (CA.nat), Number of Patches (NP.nat) of semi-natural habitats, frequency of pesticide application, and percentage of canopy cover. GLM analysis was conducted using R statistical software (R Core Team 2024).

RESULTS AND DISCUSSION

Diversity and population density of fruit flies in apple orchard

Three species of fruit flies were found in the study sites with a total of 8051 individuals. The most abundant species of fruit flies were *B. carambolae* (4636 individuals) (Figure 4.A), followed by *B. dorsalis* (3408 individuals) (Figure 4.B). The species with the least number of individuals was

B. umbrosa (7 individuals) (Figure 4.C), which was found in only one study site. However, based on the host-rearing method, only two species of fruit flies were found to attack apple fruits, namely *B. carambolae* and *B. dorsalis*, and one parasitoid species, *Fopius* sp.

The population density and spatial variation of *B. carambolae* and *B. dorsalis* differed among apple orchards (Figure 5). The population density of *B. carambolae* was significantly different in each research site ($F=36.94$; $P<0.001$), where the highest population density was found in Taman with 79.22 individuals, while the lowest was found in Bengkaras with 7.28 individuals. The population density of *B. dorsalis* was significantly different in each research site ($F=24.52$; $P<0.001$), where the highest population density was found in Putur, with 47.78 individuals, while the lowest was found in Bengkaras, with 5.56 individuals. According to the CV value, the spatial variation of population density of *B. carambolae* in Borah and *B. dorsalis* in Junggo showed a high variation among traps within an apple orchard (heterogeneous) but not significantly different in each research site ($F=1.56$; $P: 0.26$). In addition, the spatial variation of the population density of *B. carambolae* in Bulukerto and *B. dorsalis* in Taman showed a low variation among traps within an apple orchard (homogeneous) and were not significantly different in each research site ($F=1.19$; $P: 0.39$).

Effect of local and landscape factors on population density of fruit flies

For local factors, the highest pesticide application was found in Jurangrejo and Taman, and the highest canopy cover was found in Borah. For landscape characterization, the landscape composition of the study sites was dominated by the land use category apple orchard because all sites consisted of apple orchards with variations in area, where the highest was for the apple orchard in Gerdu (Figure 3). Semi-natural habitat land use was found in several study sites, with the highest being in Blarang. Only the CA and NP of the apple orchard and semi-natural habitat categories were utilized in the analysis.

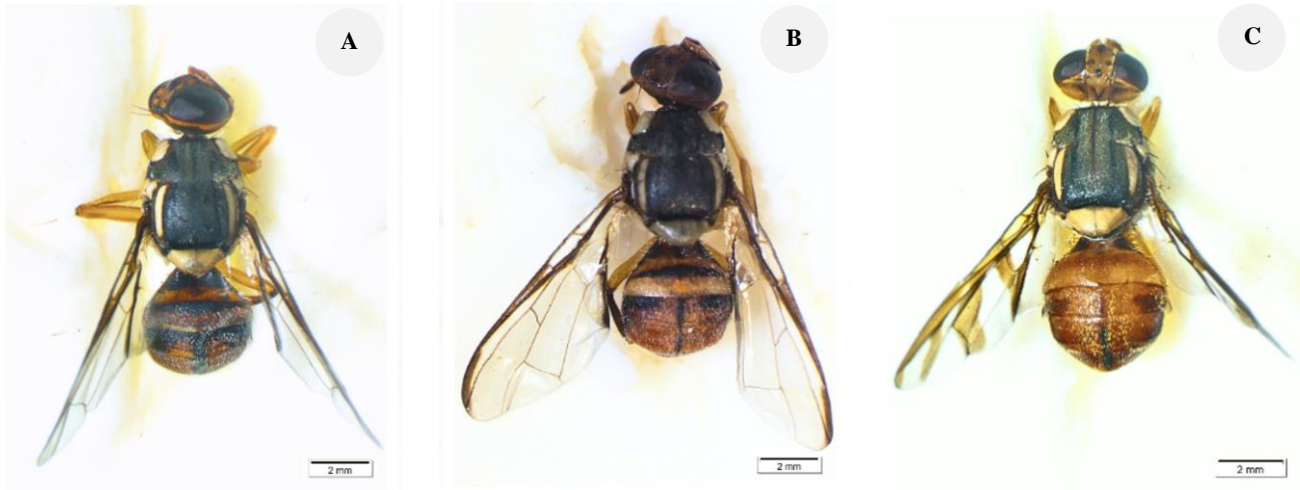


Figure 4. Morphology of fruit fly: A. *Bactrocera carambolae*; B. *Bactrocera dorsalis*; C. *Bactrocera umbrosa*

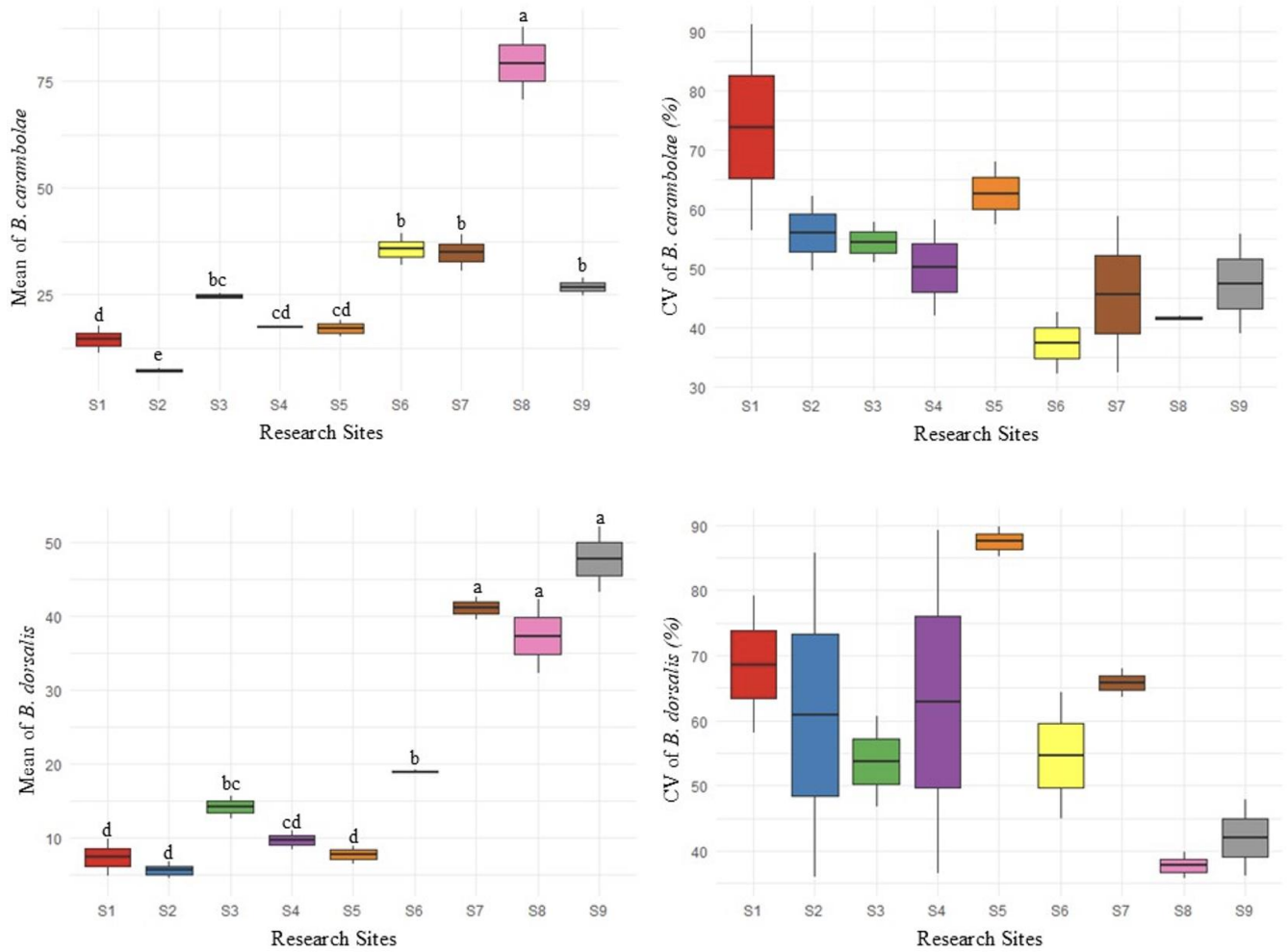


Figure 5. Population density of *Bactrocera carambolae* and *Bactrocera dorsalis* in the nine research sites, show mean, standard deviation, and coefficient of variations (CV). Site codes: S1: Borah, Malang; S2: Bengkaras, Malang; S3: Jurangrejo, Malang; S4: Gerdu, Batu; S5: Junggo, Batu; S6: Bulukerto, Batu; S7: Blarang, Pasuruan; S8: Taman, Pasuruan; S9: Putur, Pasuruan

Table 2. Generalized linear models relating population density and spatial variation of fruit flies to landscape factors (class area (CA.nat) and number of patches (NP.nat) of semi-natural habitats and class area (CA.apple) and number of patches (NP.apple) of apple orchards) and local factors (frequency of pesticide application and canopy cover)

	<i>Bactrocera carambolae</i>						<i>Bactrocera dorsalis</i>					
	Population density			CV of population density			Population density			CV of population density		
	Est	SE	P	Est	SE	P	Est	SE	P	Est	SE	P
(Intercept)	4.572	0.38	0.000	3.013	0.44	0.000	3.238	0.96	0.005	4.305	0.63	0.000
CA.nat	0.044	0.01	0.000 **	-0.014	0.01	0.035 *	0.051	0.01	0.001 *	-0.004	0.01	0.667
NP.nat	-0.735	0.11	0.000 **	0.121	0.11	0.290	-0.098	0.22	0.659	0.011	0.18	0.950
CA.orchard	0.172	0.05	0.004 *	-0.028	0.03	0.425	0.070	0.08	0.413	0.025	0.05	0.651
NP.orchard	-0.252	0.06	0.001 *	0.053	0.04	0.240	-0.104	0.10	0.331	-0.029	0.07	0.677
Pesticide	0.622	0.09	0.000 **	-0.099	0.08	0.223	0.146	0.17	0.397	-0.043	0.13	0.740
Canopy	-0.037	0.01	0.000 **	0.016	0.01	0.023 *	-0.018	0.02	0.243	0.001	0.01	0.906

Est: Estimate; SE: Standard Error; P: P-value, *P <0.05; **P <0.001.

GLM analysis showed that local and landscape factors affected the population density of *B. carambolae* and *B. dorsalis* differently. The landscape factor of the presence of semi-natural habitats surrounding the apple orchard significantly influenced the population densities of both *B. carambolae* and *B. dorsalis* fruit flies. The CA of semi-natural habitats had a positive effect on the populations of *B. carambolae* (P: 0.000) and *B. dorsalis* (P: 0.001), while the NP of the semi-natural habitats had only a negative effect on the population density of *B. carambolae* (P: 0.000). Furthermore, the CA and NP of apple orchards also only affected the population of *B. carambolae*. Increasing the CA of apple orchards tended to increase the population density of *B. carambolae* (P: 0.004), while increasing the NP of apple orchards tended to decrease the population density of *B. carambolae* (P: 0.001) (Table 2). The local factors, in this case, pesticide application and canopy cover, also only affected the population density of *B. carambolae* and not *B. dorsalis*. Pesticide application causes an increase *B. carambolae* population (P: 0.000), while canopy cover causes a decrease in its population (P: 0.000).

In relation to the spatial variation of fruit fly population density, local and landscape factors also only affected the *B. carambolae* species. A landscape factor, the CA of semi-natural habitats, had a negative effect (P: 0.035) on the variation of *B. carambolae* population density among trees within an apple orchard, while local factor, canopy cover, had a positive effect on population variation (P: 0.023).

Discussion

In this study, two species of fruit flies attacking apple crops were found: *B. carambolae* and *B. dorsalis*. Both species dominate the research sites because they have a wide distribution and polyphagous nature that allows them to have a wide range of alternative hosts (Kim and Kim 2018; Sari et al. 2020). Research by Koswanudin et al. (2018) showed that *B. carambolae* preferred fruits from the Rosaceae family, including apples. Research by Clarke et al. (2005) also showed that *B. dorsalis* was found during host-rearing on apple fruit.

Based on the results of the study, it was found that *B. dorsalis* was influenced by only one factor (class area of semi-natural habitat), in contrast to *B. carambolae*, which

was influenced by many factors (landscape composition and the local scale factors of pesticide application and canopy cover). This is because *B. dorsalis* has high adaptability, and thus, changes in factors do not significantly affect the population of *B. dorsalis* (Leblanc et al. 2015). One mechanism that supports this adaptability is the sensitivity of *B. dorsalis* to pheromones, which allows it to detect potential mates or resources efficiently, even under changing environmental conditions (Haq et al. 2016; Jaffar et al. 2023). Research by Vargas et al. (2015) and Koswanudin et al. (2018) had shown that *B. carambolae* is more specialized in its ecological needs, making it more vulnerable to environmental changes. This specialization may lead to greater vulnerability when faced with extreme environmental conditions, resulting in more pronounced impacts on its population when compared to the more adaptable *B. dorsalis*.

Knowing the factors that influence fruit fly population density in apple orchards is key to developing effective management strategies (Valiuškaite et al. 2017; Araujo et al. 2019). Population density serves as an important indicator of pest pressure and ecosystem health; it also allows quantification of pest pressure, helps determine the severity of infestations, and guides intervention decisions. By monitoring population density over time, trends and early warning signs of potential pest outbreaks can be identified for pest management (Onufrieva and Onufriev 2021). Research by Susanto et al. (2022) showed differences in population densities among various locations caused by local environmental factors, host availability, and interspecific competition.

The coefficient of variation plays an important role in measuring spatial variation to understand insect population distribution, with the aim of measuring population stability and spatial variation, helping to identify areas of high variability or clustering, and guiding ecological or pest management strategies (Sciarretta and Trematerra 2014). The results of this study show that the spatial variation of *B. carambolae* density in Borah and *B. dorsalis* in Junggo tends to be heterogeneous, while in Bulukerto and Taman, the spatial variation is more homogeneous. This difference suggests that pest distribution in some locations is more focused on certain areas than others, which may affect the effectiveness of pest control strategies in each apple

orchard studied. Thus, an understanding of population density and its spatial variation can be the basis for determining a more appropriate approach to pest management based on the characteristics of each study site.

One of the factors that can affect fruit fly population density is cultivation practices, which cover pesticide application, fertilizer, canopy cover, and cropping systems (Zhang et al. 2022; Rizali and Buchori 2024). Since fertilizer and cropping systems in the nine study sites were similar, the influence of fertilizers and cropping systems was not included in the factor analysis. Pesticide application can affect fruit fly population density, whereas pesticide application has a positive effect. This is because intensive pesticide application can cause fruit fly resistance and resurgence. Research by Gao et al. (2024) showed that excessive application of chemical pesticides can cause pests to become resistant to chemicals and cause a resurgence or explosion of pest populations. In addition, pesticide application may limit the fertility, fecundity, and prey consumption or parasitism, and thus, pesticide application can reduce natural enemies and beneficial insects such as pollinators and decomposers (Picchi et al. 2016; Schmidt-Jeffris 2023; Knauer et al. 2024).

Canopy cover has a correlation with air humidity, where a higher canopy cover can increase humidity and decrease light intensity (Nath and Deka 2024). Research by Ren et al. (2023) has shown that light conditions can increase fruit fly populations because copulation behaviors of fruit flies occur at high light intensities; thus, greater canopy cover has a negative effect on fruit fly populations.

Another factor that may affect fruit fly population density is landscape composition. Landscape composition is one of the factors that play an important role in determining fruit fly population density and biocontrol services such as natural enemies. Landscapes with complex structures support greater fruit fly diversity and populations compared to simple landscapes, where higher complexity of landscape can make interactions among pests, plants, and natural enemies more stable, which enhances agroecosystem stability and reduces pest attacks (Diallo et al. 2021; Ponti et al. 2024). Landscape complexity is usually measured through compositional indices such as class area and number of patches, which are used to understand the relationship between landscapes and fruit fly populations (Ulina et al. 2019). The results showed that the class area of semi-natural habitats positively affected on the population densities of *B. dorsalis* and *B. carambolae*. Yet, the class area of the apple orchard only affected the population density of *B. carambolae*. Research by Araujo et al. (2019) has shown that semi-natural habitats positively effect on the abundance of fruit flies. This is in accordance with previous research that showed that semi-natural habitats have a high availability of hosts and are always present, allowing the population of fruit flies to increase (Picchi et al. 2016). In addition, the number of patches of semi-natural habitats and apple orchards can decrease fruit fly populations. This is because the number of patches can increase landscape fragmentation (Justeau-Allaire et al. 2024). Higher fragmentation of the landscape can increase habitat isolation, thereby increasing the extinction of

species populations, which then has an impact on increasing edge area and causing population vulnerability due to adverse environmental conditions in the edge area (Ortega and Pascual 2014). Research by Paredes et al. (2023) has shown that landscapes with low fragmentation can make it easier for fruit flies to find food, build populations, and facilitate their spread without obstacles.

In accordance with the results of the research, the class area of semi-natural habitats and canopy cover influence the spatial variation of *B. carambolae* populations. Larger semi-natural habitats provide stable environmental conditions and diverse resources, thereby reducing population fluctuations and spatial variation. Research by Zida et al. (2020) has shown that the diversity of host plants within larger habitats can lead to increased stability in the spatial of fruit flies, as these habitats provide a consistent supply of resources throughout different seasons. However, greater canopy cover has a positive effect on spatial variation. Research by Schöneberg et al. (2020) and Inskip et al. (2021) showed that fruit flies take shelter under the canopy because it provides protection when the temperature and light intensity are too high, which causes fruit flies to accumulate in one area.

In conclusion, local and landscape factors significantly influence fruit fly populations of *B. carambolae* and *B. dorsalis* in apple orchards. However, *B. dorsalis* was primarily affected by the presence of semi-natural habitats due to its high adaptability. Local factors, such as pesticide application and canopy cover also affect the population density of *B. carambolae*. Furthermore, canopy cover may contribute to increased spatial variation in *B. carambolae* population. The composition of the landscape, including the area of different habitat classes and the number of patches, can help maintain stable populations and reduce spatial variation of *B. carambolae* and spatial variation stable. These findings suggest that integrated pest management should prioritize reducing pesticide use, enhancing canopy cover, and maximizing landscape fragmentation to effectively control different species of fruit flies in apple orchards effectively.

ACKNOWLEDGEMENTS

The authors would like to thank all the farmers and landowners of apple orchards who allowed the research to be carried out in their fields, as well as all those who helped to carry out and prepare this research.

REFERENCES

- Al-Khoury C, Nemer N, Nemer G. 2021. Beauvericin potentiates the activity of pesticides by neutralizing the ATP-binding cassette transporters in arthropods. *Sci Rep* 11 (1): 10865. DOI: 10.1038/s41598-021-89622-5.
- Araujo ES, Monteiro LB, Monteiro RS, Nishimura G, Franck P, Lavigne C. 2019. Impact of native forest remnants and wild host plants on the abundance of the South American fruit fly, *Anastrepha fraterculus* in Brazilian apple orchards. *Agric Ecosyst Environ* 275: 93-99. DOI: 10.1016/j.agee.2019.02.007.

- Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, White J-SS. 2009. Generalized linear mixed models: A practical guide for ecology and evolution. *Trends Ecol Evol* 24 (3): 127-135. DOI: 10.1016/j.tree.2008.10.008.
- Central Statistics Agency of East Java. 2023. *Statistika Pertanian Hortikultura*. <https://jatim.bps.go.id/statictable/2023/03/20/2569/produksi-buah-buahan-alkukat-anggur-apel-menurut-kabupaten-kota-dan-jenis-tanaman-di-provinsi-jawa-timur-kwintal-2021-dan-2022.html>. [Indonesian]
- Clarke AR, Armstrong KF, Carmichael AE, Milne JR, Raghu S, Roderick GK, Yeates DK. 2005. Invasive phytophagous pests arising through a recent tropical evolutionary radiation: The *Bactrocera dorsalis* complex of fruit flies. *Ann Rev Entomol* 50: 293-319. DOI: 10.1146/annurev.ento.50.071803.130428.
- Crum NJ, Neyman LC, Gowan TA. 2021. Abundance estimation for line transect sampling: A comparison of distance sampling and spatial capture-recapture models. *Plos One* 16 (5): e0252231. DOI: 10.1371/journal.pone.0252231.
- Diallo I, Ndiaye A, Faye E, Faye M, Sembene M. 2021. Does landscape factors drive the genetic diversity and structure of populations of fruit flies, Senegal? Exploratory study of the case of *Bactrocera dorsalis* (Hendel, 1912) in the Niayes, Senegal *J Entomol Zool Stud* 9 (6a): 47-52. DOI: 10.22271/j.ento.2021.v9.i6a.8883.
- Egartner A, Lethmayer C, Gottsberger RA, Blümel S. 2019. Survey on *Bactrocera* spp. (Tephritidae, Diptera) in Austria. *EPPO Bull* 49 (3): 578-584. DOI: 10.1111/epp.12604.
- Follett PA, Pinero J, Souder S, Jamieson L, Waddell B, Wall M. 2019. Host status of 'Scifresh' apples to the invasive fruit fly species *Bactrocera dorsalis*, *Zeugodacus cucurbitae*, and *Ceratitis capitata* (Diptera: Tephritidae). *J Asia Pac Entomol* 22: 458-470. DOI: 10.1016/j.aspen.2019.01.019.
- Gao Y, Su S, Xing J, Liu Z, Nässel DR. 2024. Pesticide-induced resurgence in brown planthopper is mediated by action on a suite of genes that promote juvenile hormone biosynthesis. *eLife* 12: RP91774. DOI: 10.1101/2023.06.21.545881.
- Grechi I, Preterre AL, Lardenois M, Ratnadass A. 2022. *Bactrocera dorsalis* invasion increased fruit fly incidence on mango production in Reunion Island. *Crop Prot* 161: 106056. DOI: 10.1016/j.cropro.2022.106056.
- Haq IU, Vreysen MJB, Schutze M, Hendrichs J, Shelly T. 2016. Effects of methyl eugenol feeding on mating compatibility of Asian population of *Bactrocera dorsalis* (Diptera: Tephritidae) with African population and with *B. carambolae*. *J Econ Entomol* 109: 148-153. DOI: 10.1093/jee/tov274.
- Inskip JR, Allen AP, Taylor PW, Rempoulakis P, Weldon CW. 2021. Canopy distribution and microclimate preferences of sterile and wild Queensland fruit flies. *Sci Rep* 11: 1-14. DOI: 10.1038/s41598-021-92218-8.
- Jaffar S, Rizvi SAH, Lu Y. 2023. Understanding the invasion, ecological adaptations, and management strategies of *Bactrocera dorsalis* in China: A review. *Horticulturae* 9 (9): 1-23. DOI: 10.3390/horticulturae9091004.
- Jung M. 2013. LecoS-A QGIS plugin for automated landscape ecology analysis. *PeerJ Prepr* 2: 1-10. DOI: 10.7287/peerj.preprints.116v2.
- Justeau-Allaire D, Ibanez T, Vieilledent G, Lorca X, Birnbaum P. 2024. Refining intra-patch connectivity measures in landscape fragmentation and connectivity indices. *Landsc Ecol* 39: 1-18. DOI: 10.1007/s10980-024-01840-0.
- Kim SB, Kim DS. 2018. A tentative evaluation for population establishment of *Bactrocera dorsalis* (Diptera: Tephritidae) by its population modeling: Considering the temporal distribution of host plants in a selected area in Jeju, Korea. *J Asia Pac Entomol* 21: 451-465. DOI: 10.1016/j.aspen.2018.01.022.
- Knauer A, Naef C, Albrecht M. 2024. Pesticide hazard, floral resource availability and natural enemies interactively drive the fitness of bee species depending on their crop fidelity. *Sci Total Environ* 922: 171058. DOI: 10.1016/j.scitotenv.2024.171058.
- Koswanudin D, Basukriadi A, Samudra IM, Ubaidillah R. 2018. Host preference fruit flies *Bactrocera carambolae* (Drew & Hancock) and *Bactrocera dorsalis* (Drew and Hancock) (Diptera: Tephritidae). *Jurnal Entomologi Indonesia* 15 (1): 40-49. DOI: 10.5994/jei.15.1.40.
- Krasnov H, Cohen Y, Goldshtein E, Mendelsohn O, Silberstein M, Gazit Y, Blank L. 2019. The effect of local and landscape variables on Mediterranean fruit fly dynamics in citrus orchards utilizing the ecoinformatics approach. *J Pest Sci* 92: 453-463. DOI: 10.1007/s10340-018-1023-8.
- Leblanc L, Jose MS, Barr N, Rubinoff D. 2015. A phylogenetic assessment of the polyphyletic nature and intraspecific color polymorphism in the *Bactrocera dorsalis* complex (Diptera, tephritidae). *Zookeys* 540: 339-367. DOI: 10.3897/zookeys.540.9786.
- Li BH, Zhang ZF, Xu XM. 2024. Developing and implementing an integrated pest/disease management in apple for smallholder farms in Yantai, China. *Crop Prot* 182: 106668. DOI: 10.1016/j.cropro.2024.106668.
- Louzeiro LRF, Souza-Filho MF, Raga A, Gisloti LJ. 2021. Incidence of frugivorous flies (Tephritidae and Lonchaeidae), fruit losses and the dispersal of flies through the transportation of fresh fruit. *J Asia Pac Entomol* 24: 50-60. DOI: 10.1016/j.aspen.2020.11.006.
- Mitchell MGE, Hartley E, Tsuruda M, Gonzalez A, Bennett EM. 2022. Contrasting responses of soybean aphids, primary parasitoids, and hyperparasitoids to forest fragments and agricultural landscape structure. *Agric Ecosyst Environ* 326: 107752. DOI: 10.1016/j.agee.2021.107752.
- Mutamiswa R, Nyamukondiwa C, Chikowore G, Chidawanyika F. 2021. Overview of oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Africa: From invasion, bio-ecology to sustainable management. *Crop Prot* 141: 105492. DOI: 10.1016/j.cropro.2020.105492.
- Nath R, Deka S. 2024. Understanding urban atmospheric variability: Implications of vegetation (canopy cover) dynamics in Assam's urban landscapes. *Environ Sustain Indic* 24: 100519. DOI: 10.1016/j.indic.2024.100519.
- Onufrieva KS, Onufriev A V. 2021. How to count bugs: A method to estimate the most probable absolute population density and its statistical bounds from a single trap catch. *Insects* 12 (10): 932. DOI: 10.3390/insects12100932.
- Ortega M, Pascual S. 2014. Spatio-temporal analysis of the relationship between landscape structure and the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae). *Agric For Entomol* 16: 14-23. DOI: 10.1111/afe.12030.
- Paredes D, Alves JF, Mendes S, Costa JM, Alves J, da Silva AA, Sousa JP. 2023. Landscape simplification increases *Bactrocera oleae* abundance in olive groves: Adult population dynamics in different land uses. *J Pest Sci* 96: 71-79. DOI: 10.1007/s10340-022-01489-1.
- Perez-Alvarez R, Nault BA, Poveda K. 2018. Contrasting effects of landscape composition on crop yield mediated by specialist herbivores. *Ecol Appl* 28: 842-853. DOI: 10.1002/eap.1695.
- Petrovskii S, Petrovskaya N, Bearup D. 2014. Multiscale approach to pest insect monitoring: Random walks, pattern formation, synchronization, and networks. *Phys Life Rev* 11: 467-525. DOI: 10.1016/j.plrev.2014.02.001.
- Picchi MS, Bocci G, Petacchi R, Entling MH. 2016. Effects of local and landscape factors on spiders and olive fruit flies. *Agric Ecosyst Environ* 222: 138-147. DOI: 10.1016/j.agee.2016.01.045.
- Plant Health Australia. 2018. *The Australian Handbook for the Identification of Fruit Flies* (3.1 ed.). Plant Health Australia, Canberra.
- Ponti L, Gutierrez AP, Giannakopoulos C, Varotsos KV, López NJ, López FS, Rivas GFW, Caboni F, Stocchino F, Rosati A, Marchionni D, Cure JR, Rodríguez D, Terrado M, De Felice M, Dell'Aquila A, Calmanti S, Arjona R, Sanderson M. 2024. Prospective regional analysis of olive and olive fly in Andalusia under climate change using physiologically based demographic modeling powered by cloud computing. *Clim Serv* 34: 100455. DOI: 10.1016/j.cliser.2024.100455.
- Pujiastuti Y, Irsan C, Herlinda S, Kartini L, Yulistin E. 2020. Keanekaragaman dan pola keberadaan lalat buah (Diptera: Tephritidae) di Provinsi Sumatera Selatan. *Jurnal Entomologi Indonesia* 17 (3): 125. DOI: 10.5994/jei.17.3.125.
- R Core Team. 2024. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna. <https://www.r-project.org/>. [Austria]
- Ramadan MM, Hoelmer KA, Wang X. 2023. Host immunity, non-reproductive effects and kleptoparasitism from novel interactions: A case study with the fruit fly parasitoid *Psyttalia fetcheri* (Hymenoptera: Braconidae). *Biol Control* 108: 105307.
- Ren C, Zhang J, Yuan JX, Wu YQQG, Yan SC, Liu W, Wang GR. 2023. Light intensity regulates the sexual behaviors of oriental fruit fly *Bactrocera dorsalis* under laboratory conditions. *J Integr Agric* 22: 2772-2782. DOI: 10.1016/j.jia.2023.04.025.

- Rizali A, Buchori D. 2024. Host-parasitoid food webs in oil palm plantations in Asia. *Curr Opin Insect Sci* 66: 101272. DOI: 10.1016/j.cois.2024.101272.
- Rueden CT, Schindelin J, Hiner MC, DeZonia BE, Walter AE, Arena ET, Eliceiri KW. 2017. ImageJ2: ImageJ for the next generation of scientific image data. *BMC Bioinform* 18: 529. DOI: 10.1186/s12859-017-1934-z.
- Sari EK, Affandi M, Hariyanto S. 2020. Diversity of fruit flies (Tephritidae: *Bactrocera* spp.) in campus C of Airlangga University, Surabaya, Indonesia. *Treubia* 47 (2): 111-122. DOI: 10.14203/treubia.v47i2.3982.
- Schmidt-Jeffris RA. 2023. Nontarget pesticide impacts on pest natural enemies: progress and gaps in current knowledge. *Curr Opin Insect Sci* 58: 101056. DOI: 10.1016/j.cois.2023.101056.
- Schöneberg T, Arsenault-Benoit A, Taylor CM, Butler BR, Dalton DT, Walton VM, Petran A, Rogers MA, Diepenbrock LM, Burrack HJ, Leach H, Van Timmeren S, Fanning PD, Isaacs R, Gress BE, Bolda MP, Zalom FG, Roubos CR, Evans RK, Sial AA, Hamby KA. 2020. Pruning of small fruit crops can affect habitat suitability for *Drosophila suzukii*. *Agric Ecosyst Environ* 294: 106860. DOI: 10.1016/j.agee.2020.106860.
- Sciarretta A, Trematerra P. 2014. Geostatistical tools for the study of insect spatial distribution: Practical implications in the integrated management of orchard and vineyard pests. *Plant Prot Sci* 50: 97-110. DOI: 10.17221/40/2013-pps.
- Station of Meteorology Climatology and Geophysics Agency in East Java Province. 2023. Data Rata-Rata Seluruh 11 Stasiun BMKG di Provinsi Jawa Timur. <https://webapi.bps.go.id>. [Indonesian]
- Susanto A, Permana A, Subahar T, Christianus R, Soesilohadi H, Amin S, Fernandes A. 2022. Population dynamics and projections of fruit flies *Bactrocera dorsalis* and *B. carambolae* in Indonesian mango plantation. *Agric Nat Res* 56 (1): 169-179. DOI: 10.34044/j.anres.2021.56.1.16.
- Tan H, Qi X. 2023. Synergistic interconstruction of the green development concept in Chinese rural ecological agriculture. *Sustainability* 15 (5): 3961. DOI: 10.3390/su15053961.
- Ulina ES, Rizali A, Manuwoto S, Pudjianto, Buchori D. 2019. Does composition of tropical agricultural landscape affect parasitoid diversity and their host-parasitoid interactions? *Agric For Entomol* 21: 318-325. DOI: 10.1111/afe.12334.
- Valiuškaite A, Uselis N, Kviklys D, Lanauskas J, Rasiukevičiute N. 2017. Aplinką tausojančios augalų apsaugos sistemos ir obelų auginimo technologijos taikymo įtaka vaisių kokybei bei derliui. *Zemdirbyste-Agriculture* 104: 353-358. DOI: 10.13080/z-a.2017.104.045.
- Vargas RI, Piñero JC, Leblanc L. 2015. An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the pacific region. *Insects* 6 (2): 297-318. DOI: 10.3390/insects6020297.
- Zhang X, Ouyang F, Su J, Li Z, Yuan Y, Sun Y, Sarkar SC, Xiao Y, Ge F. 2022. Intercropping flowering plants facilitate conservation, movement and biocontrol performance of predators in insecticide-free apple orchard. *Agric Ecosyst Environ* 340: 108157. DOI: 10.1016/j.agee.2022.108157.
- Zida I, Nacro S, Dabiré R, Moquet L, Delatte H, Somda I. 2020. Host range and species diversity of Tephritidae of three plant formations in Western Burkina Faso. *Bull Entomol Res* 110 (6): 732-742. DOI: 10.1017/S0007485320000243.